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NUCLEAR FLASH EYE EFFECTS TECHNICAL REPORT FOR MILITARY PLANNERS

RALPH G. ALLEN, JR.

DAVID E. JUNGBAUER

DONALD J. ISGITT

BRIAN E. ARMENT

JOHN A. RUSSELL

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USAF School of Aerospace Medicine
Aerospace Medical Division (AFSC)
Brooks Air Force Base, Texas

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Allen, R. G., Jr., D. E. Jungbauer,
D. J. Isgitt, B. E. Arment, and J. A. Russell

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FOREWORD

This report was prepared by personnel of the Life Sciences Division of Technology Incorporated--

Ralph G. Allen, Jr., Ph.D.

David E. Jungbauer, B.S.

Donald J. Isgitt, B.S.

Brian E. Arment, B.A.

John A. Russell, M.S.

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ABSTRACT

This report is intended to be used as an aid to military mission planners in determining allowable proximity to a nuclear fireball from the standpoints of permanent retinal injury and the temporary effects of flashblindness. Pertinent physical and physiological phenomena are discussed in moderate detail; the nucleus of the work being a family of curves which indicate acceptable separation distances for the prevention of retinal burns and flashblindness. Detailed instructions for approximating acceptable separation distances using a slide rule are included as an appendix.

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I. INTRODUCTION

It has been known for many years that damage to the eyes can occur as a result of viewing a very bright light, and that this damage could result in a permanent loss of visual acuity. The early evidence of retinal damage produced in this way was observed in individuals who had viewed a solar eclipse without adequate eye protection[1]. The resulting loss in vision was called "eclipse blindness", and even now despite frequent warnings to the public, injuries from viewing eclipses are still reported[2].

The development of nuclear weapons introduced a new and potentially more hazardous source of radiation capable of producing eye injuries. The potential for eye injury was recognized from the beginning since protective goggles were worn at the first atomic bomb test in 1942--and in each test thereafter.

The first experiments dealing with the effects of a nuclear flash on the eyes were conducted by the Air Force School of Aviation Medicine in 1951 during Operation Buster. It appears, however, that this problem was not discussed in the open literature until 1953 when it was pointed out[3] that, because of the focusing of energy by the eye, injury could be sustained at extremely long distances--much longer distances than those at which injury could be produced by any other direct effects.

Following Operation Buster came a series of field experiments to study the effects of nuclear detonations on vision. This series of field studies

culminated with an extensive experiment conducted during Operation Dominic and Fishbowl in 1962 [4].

Today, there are several sources of radiant energy that are capable of producing retinal damage, and most of these sources possess a much greater capacity for producing damage than does the sun. With the exception of the Q-switched laser--an ultra-high power mode of laser operation that introduces a new spectrum of biological damage [5,6]--the mechanism by which injury to the eye is produced appears to be the same in all cases, viz., the production of regions of elevated temperatures in the retina and adjacent regions as a result of absorption of the incident radiation energy. Since permanent injury appears to be simply a consequence of generating excessive temperatures, no matter whether the source is the sun, a nuclear detonation, a normally operated laser, a pulsed xenon tube, an incandescent plasma, or some other high intensity source, the damage produced will be similar in each case--differing only as a result of variations in the conditions of exposure, differences in the characteristics of the sources, and differences in the subjects themselves.

The significance of chorioretinal burns depends upon a number of factors. Some of these factors are associated with the physical characteristics of the actual lesions--such as size, location, and severity. These factors determine the particular visual function affected and the extent of loss of function. In contrast, other factors involve the consequences of having

suffered a loss of visual function. These factors deal with the importance to the individual of the specific function affected, the extent of the functional loss, the possibility of partial recovery, and the potential for partly overcoming the loss by visual training and/or practice.

II. GENERAL DISCUSSION

This report was developed for use in determining acceptable proximity to nuclear detonations in so far as eye effects are concerned. Two potential mission hazards are dealt with - retinal burns and flashblindness. Weapon yields from .01 KT to 25 MT at burst and flight altitudes ranging from sea level to 100,000 feet have been considered.

The distances determined using the retinal burn envelopes are the minimum allowable distances from fireball to observer that are considered "safe", i.e., distances at which no permanent damage will be produced before a reflexive blink occurs and protects the eye.

The distances determined using the flashblindness envelopes are also minimum allowable distances, but in this case, they refer to temporary rather than permanent visual impairment. These curves describe the distance at which 10 seconds of flashblindness will be experienced, i.e. distances at which it will take 10 seconds to recover at least 20/120 acuity, sufficient acuity to obtain useful information from flight instruments.

Weapon characteristics, atmospheric transmission, and pertinent aspects of the physiology of vision are discussed cursorily in order to acquaint the reader with the basic concepts involved and to relate retinal exposure to loss of visual function.

To the extent possible, the prediction techniques employed incorporate the results of observations taken during the most recent nuclear tests [4].

Weapon Characteristics

There are several basic differences between nuclear and conventional high-explosive weapons. A nuclear explosion may be many times more powerful than the largest conventional explosion, a nuclear explosion is accompanied by highly penetrating ionizing radiations, the fission products remaining after a nuclear explosion are radioactive, and a large amount of the nuclear energy is converted to thermal energy (light and heat). This thermal energy is the energy that is responsible for chorioretinal burns and flashblindness.

Figure 1 shows the distribution of energy from a fission weapon in a typical air burst. For detonations in the atmosphere below 100,000 feet the fraction of energy converted to thermal energy lies between 30 and 40 percent [7] and is taken as 33 percent in the calculations described herein.

At lower altitudes, a gaseous fireball is formed and essentially all of the thermal energy is emitted in two pulses (Figure 2) [7]. The first

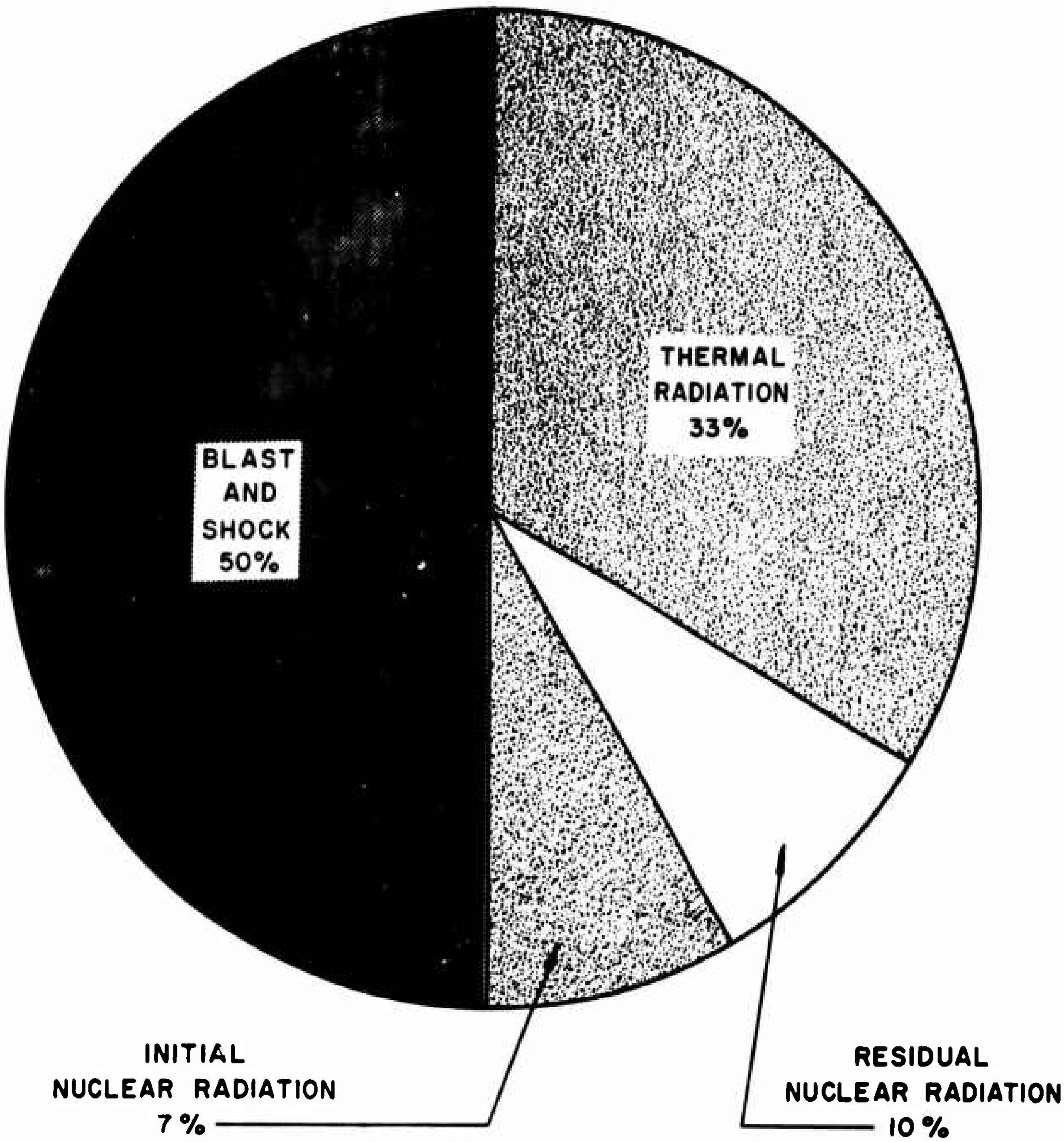


FIGURE 1. Distribution of energy in a typical air burst

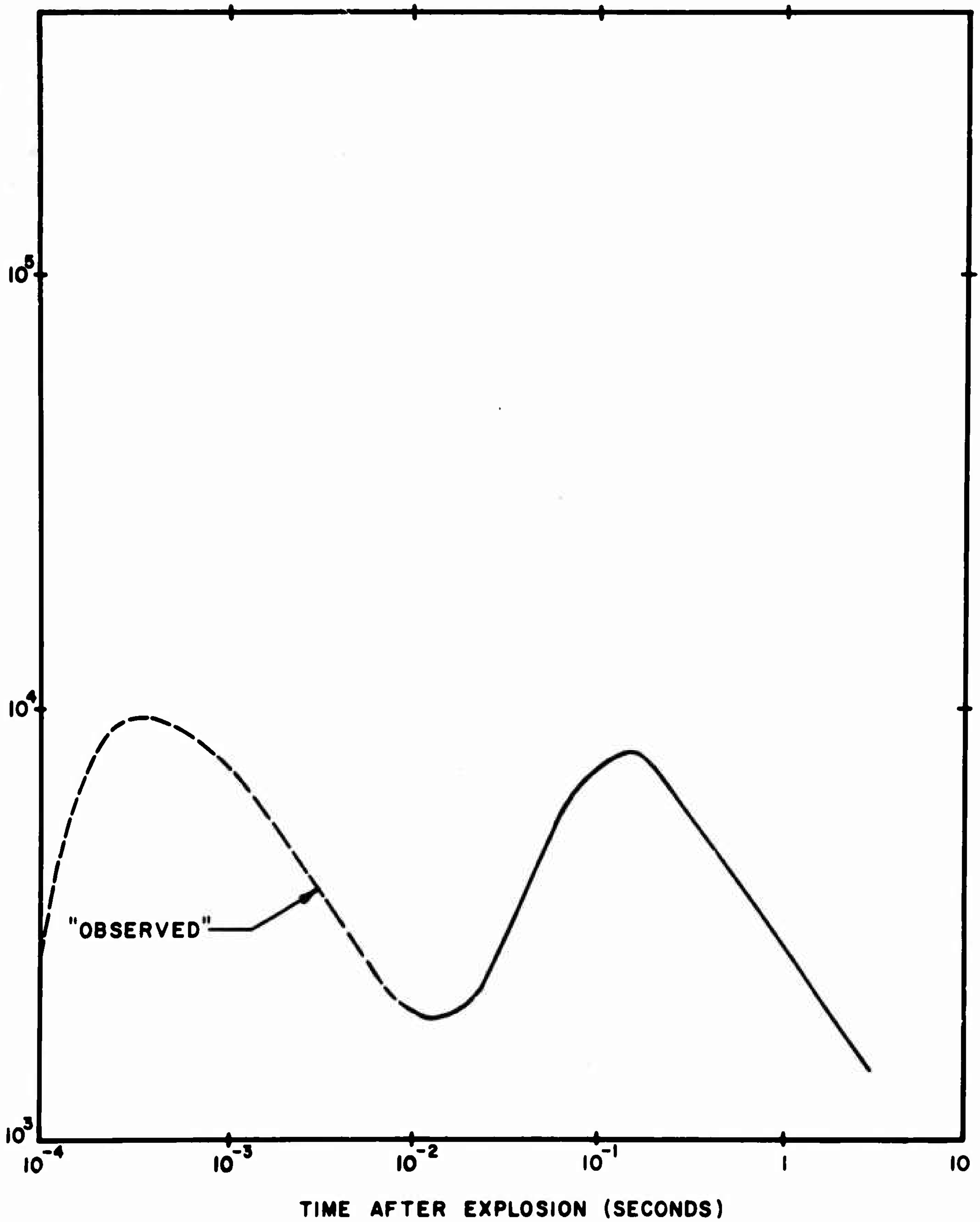


FIGURE 2. Temperature variation in a 20 kiloton air burst

pulse is relatively short and contains approximately one percent of the total energy. The second pulse, which contains the remainder of the energy, is much longer. Although the first pulse contains only one percent of the energy, under certain circumstances it is capable of producing permanent injury to the retina. For detonations at higher altitudes, more of the thermal energy appears in the first pulse. For very high altitude detonations, essentially all of the energy is emitted in a single very short pulse.

The amount of thermal energy arriving at the position of the observer depends upon the weapon design, its size, altitude of the detonation, distance to and altitude of the observer, and characteristics of the intervening atmosphere. Estimation of this energy comprises a large part of the problem of predicting safe separation distances.

Atmospheric Transmission

Before reaching the eye, the radiant energy emitted by the fireball is attenuated by the atmosphere through processes of scattering and absorption. Attenuation by the atmosphere is a subject of some complexity due to the variety of phenomena and situations which can be involved. In general, attenuation of radiant energy by the atmosphere depends upon the composition, characteristics, and distribution of the atmosphere in the path between detonation and observer and the energy spectrum of the emitted radiation. The composition, distribution, and characteristics of the atmosphere vary from time to time and place to place and frequently are difficult or impossible

to predict with any accuracy. For the retinal burn problem, it is not necessary to consider all of the phenomena involved, or to account for the full range of situations and variations which can occur. It is sufficient to limit consideration to the unscattered or image forming radiation transmitted through a clear cloudless atmosphere, the situation most favorable to the production of retinal burns, under the assumption that transmission through the atmosphere may be described adequately by the expression:

$$T_{AT} = \exp\left[-k_A^{eff} m\right] \cdot \exp\left[-k_w^{eff} w\right]$$

where:

m = the mass of air in the path between detonation and observer (a function of burst and observer altitudes and horizontal range).

w = the mass of precipitable water vapor in the path between detonation and observer (also a function of burst and observer altitudes and horizontal range).

k_A^{eff} = effective narrow beam extinction coefficient of dry air.

k_w^{eff} = effective narrow beam extinction coefficient of water vapor.

The Standard U. S. Atmosphere (1962) is used as a model for air density variation with altitude whereas an exponential decrease with altitude is assumed for water vapor density.

Interaction of Radiant Energy with the Eye

The effects of thermal radiation on the eyes may be classified as permanent (chorioretinal burns) or temporary (flashblindness). Concentration of thermal energy on the retina by the eye lens system can result in injury to the retina. However, this will normally occur only if the source of energy is in the field of vision so that an image of the source is formed on the retina. Because of the focusing of energy by the eye, the distances at which chorioretinal burns can occur may be much greater than those where thermal radiation produces skin burns. This comes about as follows: the irradiance (energy per unit area per unit time) incident on the eye is inversely proportional to the square of the distance from the fireball. However, the area of the fireball image on the retina is also inversely proportional to the square of the distance from the fireball. As a result, the irradiance at the retina in the image of the fireball is independent of the distance from the fireball--except for the effect introduced by atmospheric attenuation. Fortunately, atmospheric attenuation increases with distance so that distance can provide protection. There are two other factors which enter into the problem in a significant way--one is pupil size and the other is blink time. In order to admit more light, the pupil of the eye normally enlarges at low levels of illumination. Thus, under conditions of low ambient illumination (dusk or night) the pupil will be larger than in daylight and allow more of the thermal energy from the fireball to strike the retina. Average pupil diameters assumed for this work were 6.5 mm (night); 5 mm (behind 2% gold filter), and 2.5 mm (day).

Considering blink time, it is apparent that only radiation received prior to closing the eyes in a reflexive blink can contribute to the production of retinal damage. As a result, the time for a blink to occur can be important. For the predictions made herein, exposure times are taken to be 250 milliseconds for small weapons and 450 milliseconds for larger weapons.

III. RESULTS OF EXCESSIVE EXPOSURES

Chorioretinal Burns

A sketch of the human eye is shown in Figure 3. For purposes of discussion, the eye may be compared to a camera. Light rays received by the eye are refracted by the cornea, lens, and ocular media so that they are focused on the retina producing there an image of the fireball.

Mechanism of Production

Heat generated in the retina and adjacent structures will in time diffuse away from the area in which the image is focused and will also be conducted away by the flow of blood in the vascular bed. If the rate of heat diffusion in an area is less than the rate of heat generation in that area, the temperature will increase. If the temperature exceeds the biological tolerances for the area involved, injury to the photoreceptors (rods and cones), to the optical nerve tissue and other structures in the retina and choroid may result--with a subsequent permanent loss of vision. Current research efforts are attempting to define threshold temperatures but relatively little reliable

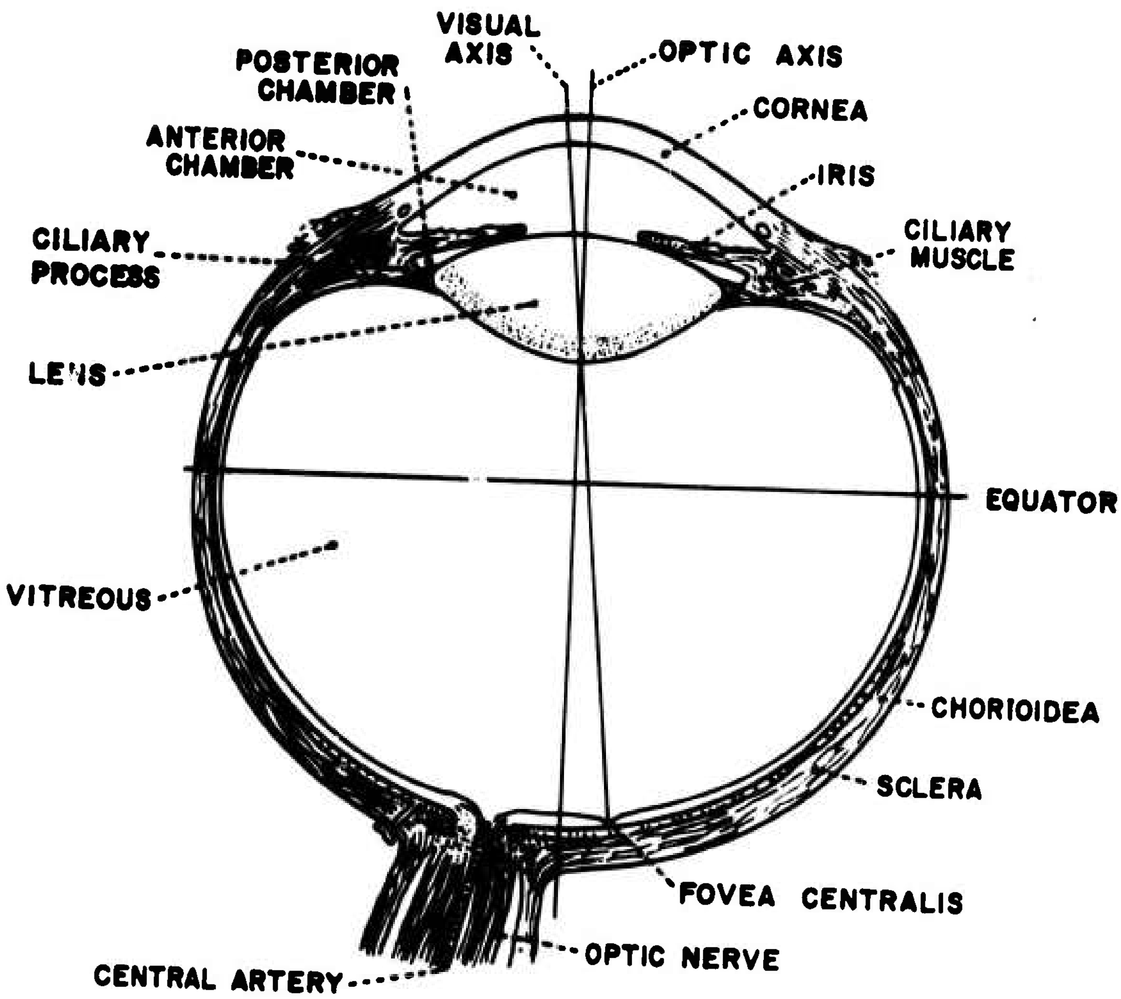


FIGURE 3. Schematic drawing of eye

quantitative information exists at present. Until more knowledge is gained in this area, it will be necessary to continue to base threshold criteria upon visual observations of retinal changes produced in laboratory animals and, with appropriate safety factors, extrapolate these results to humans.

Effects on Vision

The degree of visual impairment caused by a retinal burn will be dependent on the size, severity, and location of the burn. The size of the image, which influences the size of a burn, depends on the visual angle subtended by the object--i.e., the size of the fireball and its distance from the observer. The severity of a burn depends in general upon the amount by which the exposure exceeds the threshold exposure. The function affected will be determined by the location of the burn(s). For example, sustaining a burn in the fovea would be most detrimental to visual acuity and color vision since the fovea is employed for high acuity and color recognition. A burn in the periphery would have less effect on visual acuity, and, barring complications, could result in a scotoma or blind spot that might not be noticed. From Figure 4, it can be estimated that burns exactly centered in each fovea and large enough to include the central 2.5 degree visual field, would reduce visual acuity to about 57 percent of normal (20/35 on the Snellen scale). In theory, if the central 10 degree visual field were destroyed, the

acuity would be 29 percent (20/70). Even if the central 20 degrees of vision were destroyed, an extremely unlikely situation, visual acuity would be reduced to approximately 20 percent, i.e. about 20/100.

A schematic drawing of central field defects and the burns responsible for these defects are shown in Figure 5. The burns numbered 1-6 are shown in the region of the macula as they would appear in size and relation to the optic nerve. Burns having corresponding numbers result from a bilateral view of a single source. Corresponding scotomata are plotted on the field charts. The centrally located 1.8 mm (6 degree) burn would cause a permanent visual impairment of approximately 1/2 to 3/4 of normal if centered on the fovea. Visual acuity would probably be no better than 20/60 even after edema has subsided. Burns located off the fovea should not reduce acuity, but only produce blind spots.

Extra-foveal burns may produce visual defects that are significantly different than foveal burns. Since a lesion of the nerve fiber layer produces a defect which corresponds to the area which is served by the affected fibers and not the area of the lesion, a small heavy burn near the disc could cause an extensive field defect as well as a localized scotoma at the site of the burn. The course of the nerve fibers of the retina are shown schematically in Figure 6. Figure 7

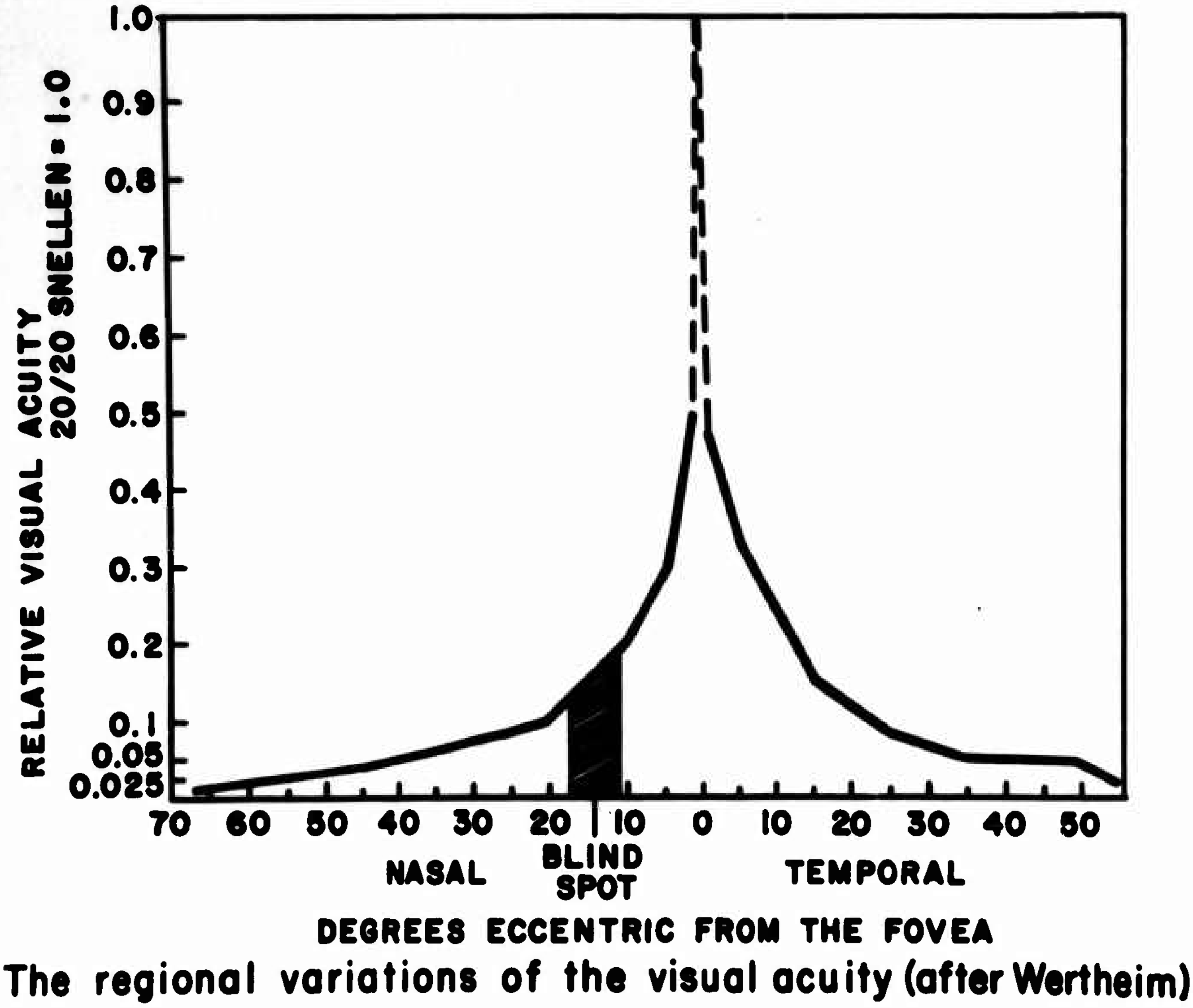
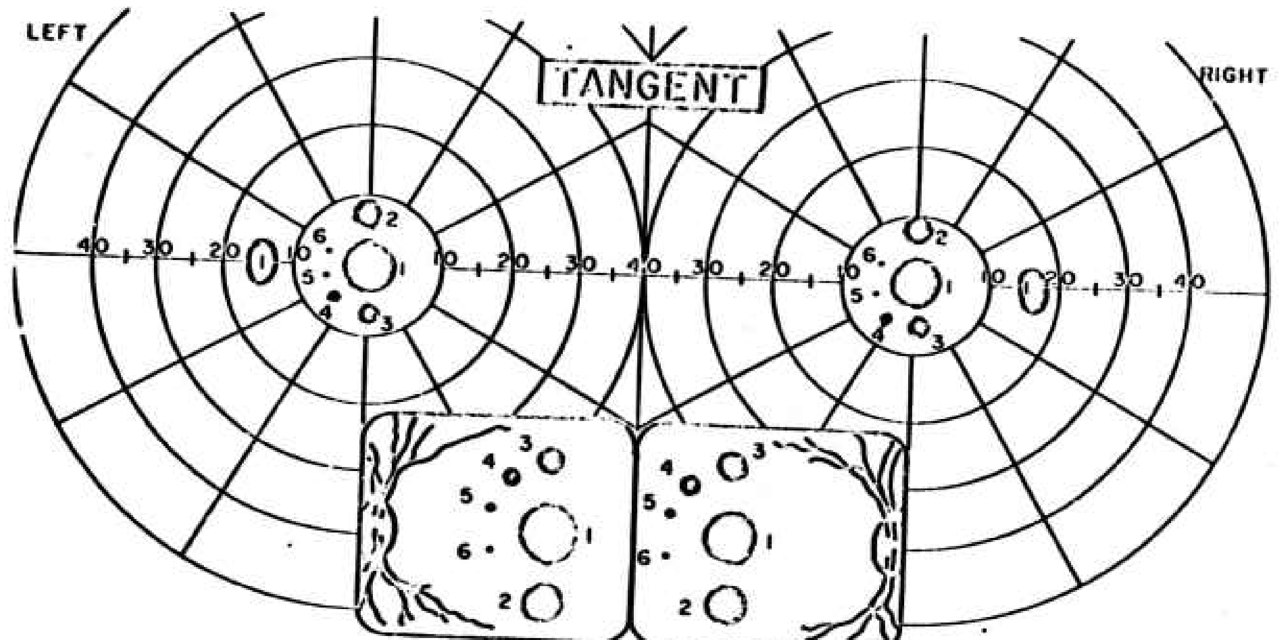


FIGURE 4. Visual acuity as a function of angular distance from the fovea.



1. - 1.8 mm BURN CAUSING CENTRAL SCOTOMA OF 6°
2. - 1.35 mm BURN CAUSING PARACENTRAL SCOTOMA OF 4.5°
3. - .9 mm BURN CAUSING PARACENTRAL SCOTOMA OF 3°
4. - .45 mm BURN CAUSING PARACENTRAL SCOTOMA OF 1.5°
5. - .15 mm BURN CAUSING PARACENTRAL SCOTOMA OF 0.5°
6. - .07 mm BURN CAUSING PARACENTRAL SCOTOMA OF 0.25°

FIGURE 5. Schematic drawings of bilateral burns and resulting visual field defects.

shows field defects produced by damage to nerve fiber bundles.

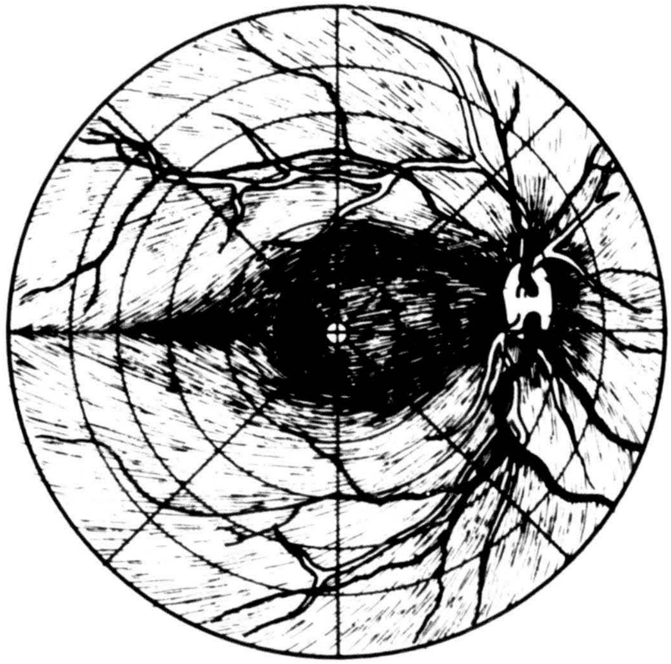
It should be emphasized that the loss of vision resulting from retinal burns although permanent and uncorrectable, will not take the form of total blindness. Burns can result in some impairment of vision in the form of blind "spots", but complete visual incapacitation as a result of retinal burns is extremely unlikely.

Flashblindness

The temporary decrease in visual sensitivity following exposure to a bright light has been termed flashblindness, and the time required to regain visual function is called recovery time. In considering recovery time, it is necessary to specify the visual task or the particular visual capability desired since the time required to reach a given level of visual performance depends upon the performance level selected.

Mechanism of Production

Briefly, high-luminance lights produce afterimages of the shape and size of the primary images. The initially perceived brightness of an afterimage is related to the amount of photo-pigment bleached in the area covered by the image, and the decrease in afterimage brightness with time appears to be related to the regeneration of the photo-pigments. An afterimage appears as a bright area in the visual field (or a dark area--depending upon the luminance of the background) and reduces



THE RADIATING LINES SHOW HOW THE NERVE FIBRES FAN OUT. NOTE THAT TEMPORAL TO THE MACULA THE FIBRES MEET IN A MEDIAN RAPHE.

Semidiagramatic picture of the Fundus Oculi, right Eye.

FIGURE 6. Schematic drawing of the nerve fibers

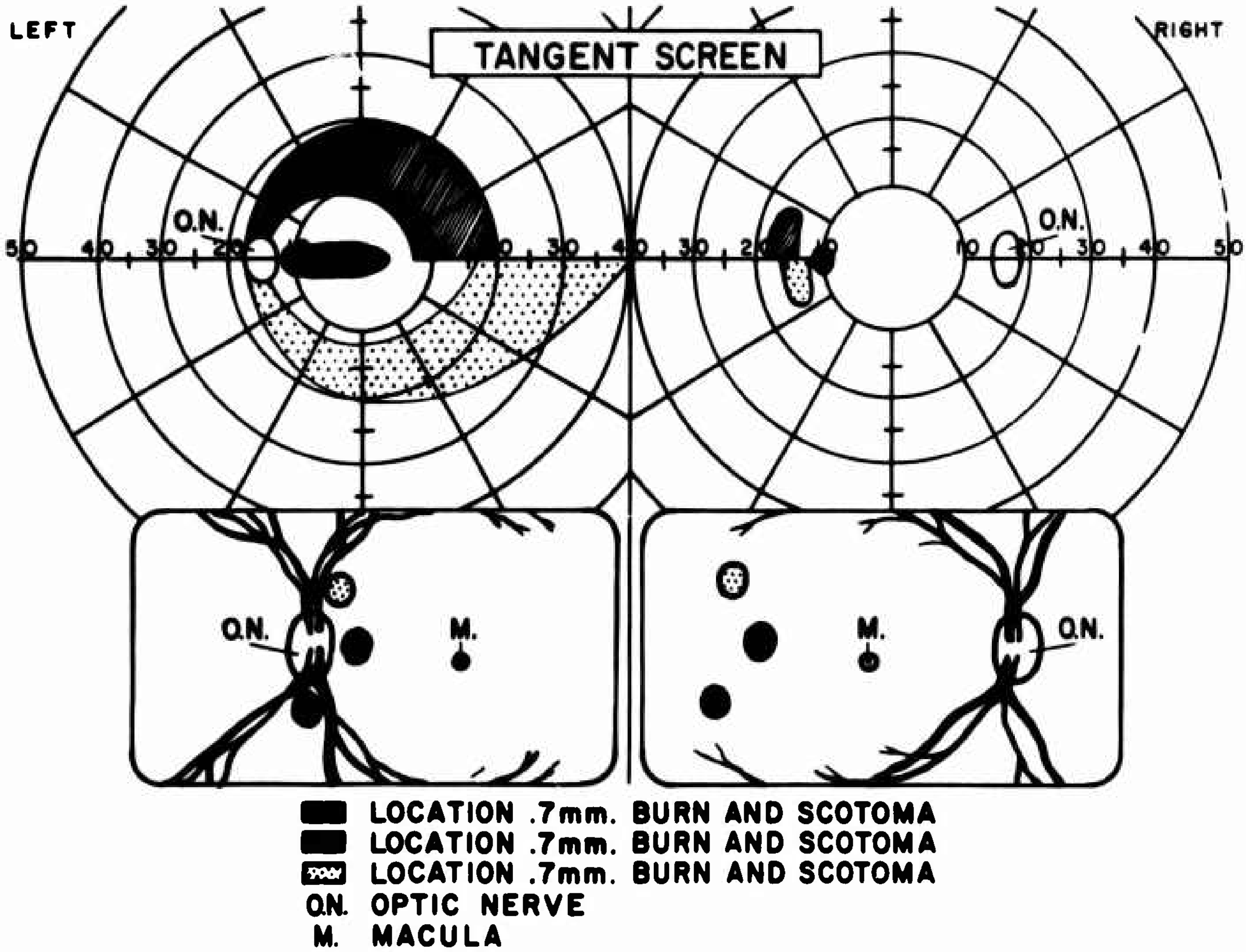


FIGURE 7. Schematic drawing of visual field defects resulting from injury to nerve-fiber bundles

contrasts in a scene subsequently imaged within the area occupied by the afterimage. In order for an object to be seen "through" the afterimage, the object must produce a primary image of sufficient brightness to create detectable contrasts. Against the background of an afterimage, detail that could be detected prior to a flash may be indistinguishable until the afterimage decays to a brightness level permitting perceivable contrasts. As a result, recovery time depends generally upon the integrated incident luminous energy, the luminance of the subsequent scene, and the visual acuity required for perception of the particular detail desired.

Effects on Vision

Figure 8 [(8)] shows the general form of recovery time as a function of stimulus flash energy--assuming a constant flash duration. Target luminance is the parameter between curves. For very low flash energies, there will be no significant effect on visual function. However, as flash energy is increased, an increase in recovery time becomes apparent. For exposure levels beyond those at which maximum bleaching occurs, recovery times may change very little with an increase in flash energy. However, as the flash energy approaches the threshold for injury, recovery time increases rapidly until injury occurs. At this point, function is lost irreversibly.

The relationship between target luminance and recovery time can also be inferred from an examination of Figure 8. Increasing display

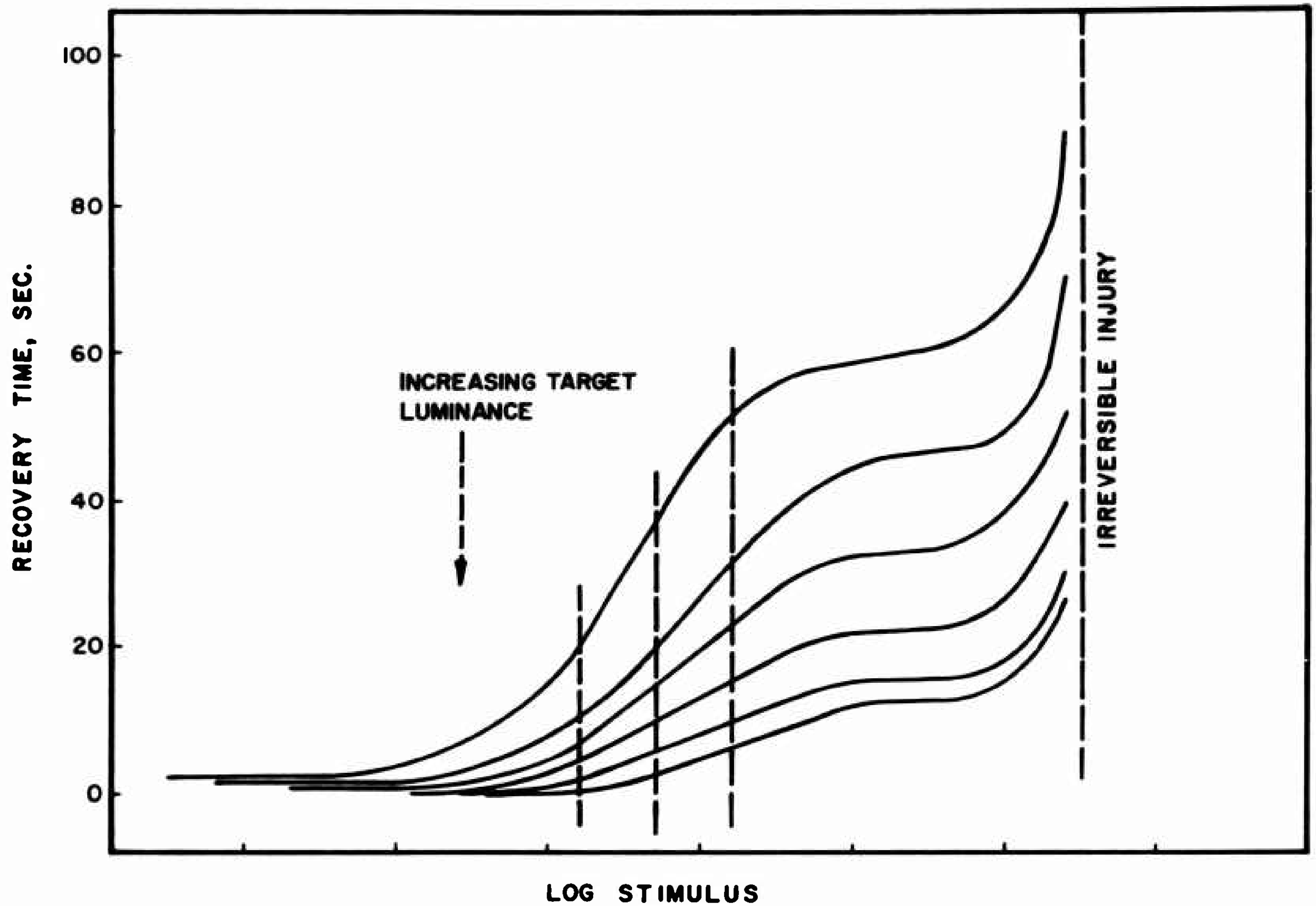


FIGURE 8. Effect of flash energy and display luminance on flashblindness recovery time

luminances are represented by successively displaced curves in the figure. Note that recovery times decrease with increasing target luminance. Clearly, target luminance is an important variable and recovery times can be significantly reduced by increasing target luminance.

IV. PREDICTION METHODS

Retinal Burn

Detailed calculations illustrating the techniques employed in determining acceptable separation distances are given in Appendix A. A brief summary of the method is given below:

The total energy per unit area focused into an image on the retina is called the retinal exposure, Q_r(CALC). This quantity varies inversely as a function of distance to the fireball due to atmospheric attenuation and can be calculated for the human eye--provided atmospheric attenuation and the thermal characteristics of the weapon are known. For the curves contained in this document, a blink reflex of 0.25 seconds is assumed for yields below 1 MT and 0.45 seconds for yields of 1 MT and above.

Experiments using rabbits, plus data obtained from limited studies involving humans, serve as the basis for determining the allowable or safe retinal exposure, Q_r^T. This is the maximum exposure for which no

burn will be produced [9].

From a practical standpoint, concern over retinal burns occurs only when there is an impairment of vision. However, the relation between impairment of function and minimal ophthalmoscopic-'' detectable lesions is not yet clearly established. To account for the inherent uncertainties, the following safety factors have been introduced:

a. Calculated retinal exposures, Q_r(CALC), are arbitrarily multiplied by a factor of two in an effort to allow for possible inadequacies in weapon data and the method of calculation. Thus $Q_r = 2Q_r$(CALC).

b. Minimal burn threshold data, determined from experiments on rabbits, are converted to human sub-threshold values by decreasing the measured threshold values, Q_r^T(MEAS), by a factor of four. Thus, $Q_r^T = Q_r^T$(MEAS)/4.

Briefly, Q_r is calculated as a function of the distance between the observer and the fireball taking into account weapon characteristics, atmospheric transmission, and properties of the eye. The allowable distance of nearest approach (safe separation distance) is then obtained by comparing values of Q_r to values of Q_r^T, also calculated as a function of the distance between observer and fireball. The safe separation distance, measured along the earth's surface, is the distance at which $Q_r = Q_r^T$.

Since Q_r is dependent on the total masses of air and water vapor in the path between detonation and observer, safe separation distances vary with both detonation altitude and observer (flight) altitude. Figure 9 illustrates the model used to take these geometrical factors into account in the results presented in Figures 13-116.

Figure 10 shows a plot of Q_r and Q_r^T vs. horizontal range. The point of intersection of these curves ($Q_r = Q_r^T$) defines the minimum allowable distance of approach for one particular burst and flight altitude combinati . To generate an "envelope" curve such as shown in Figure 11, large numbers of Q_r and Q_r^T curves must be examined. This was done using a computer program and the results are contained in Figures 13-116. For distances inside the boundaries defined by these curves, there is the possibility of eye injury as a result of retinal burns. For distances outside the boundaries, no injury is predicted.

Flashblindness

Flashblindness envelopes are generated in much the same manner as are the retinal burn envelopes, i.e., a calcualted exposure, E_r, is compared to an allowable exposure, E_r^A. However, in this case, the calculation of the exposure is somewhat more complicated than in the case for retinal burns. A brief description of the approach is given here with a detailed description appearing in Appendix B.

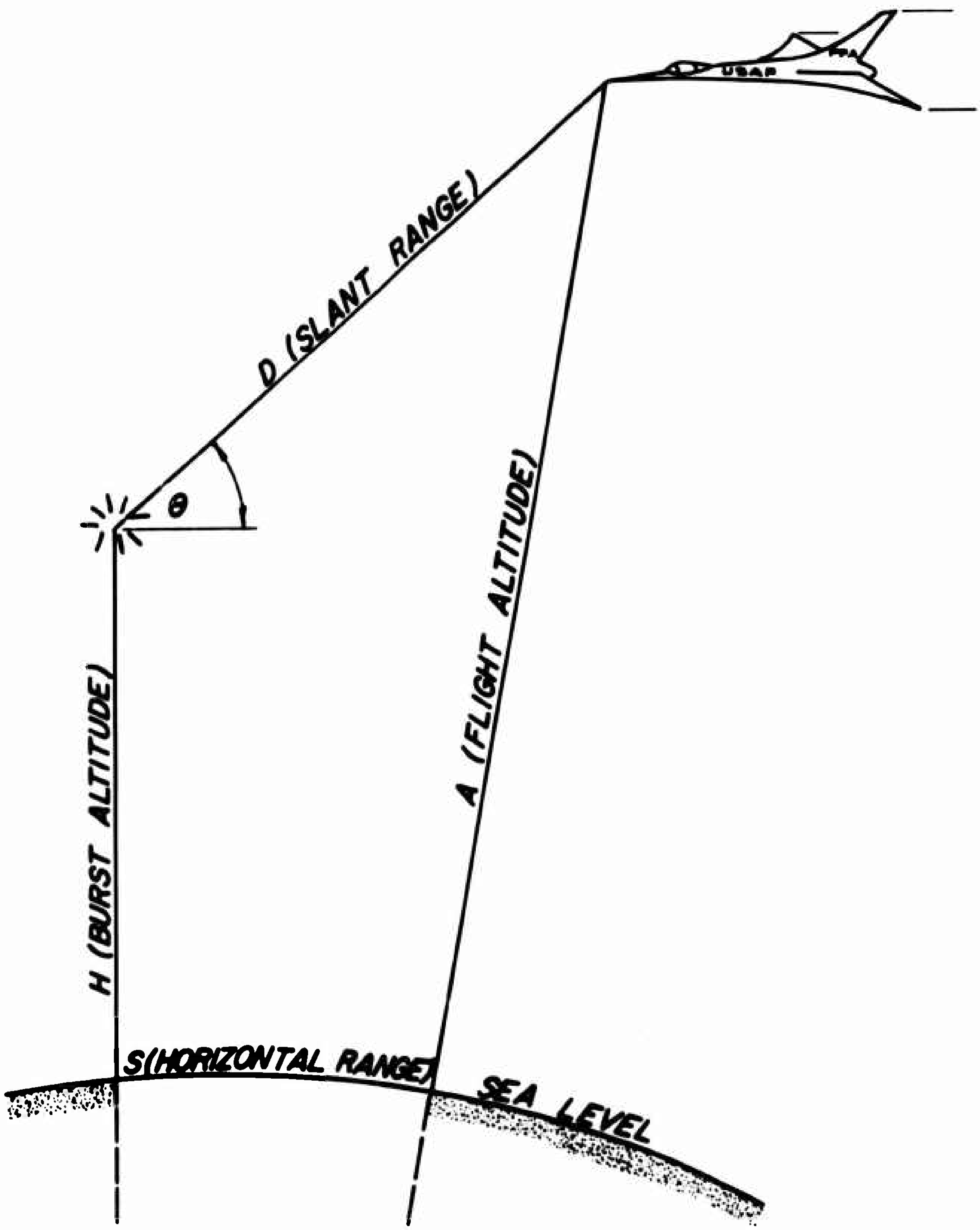


FIGURE 9. Model used for calculating transmission of the atmosphere

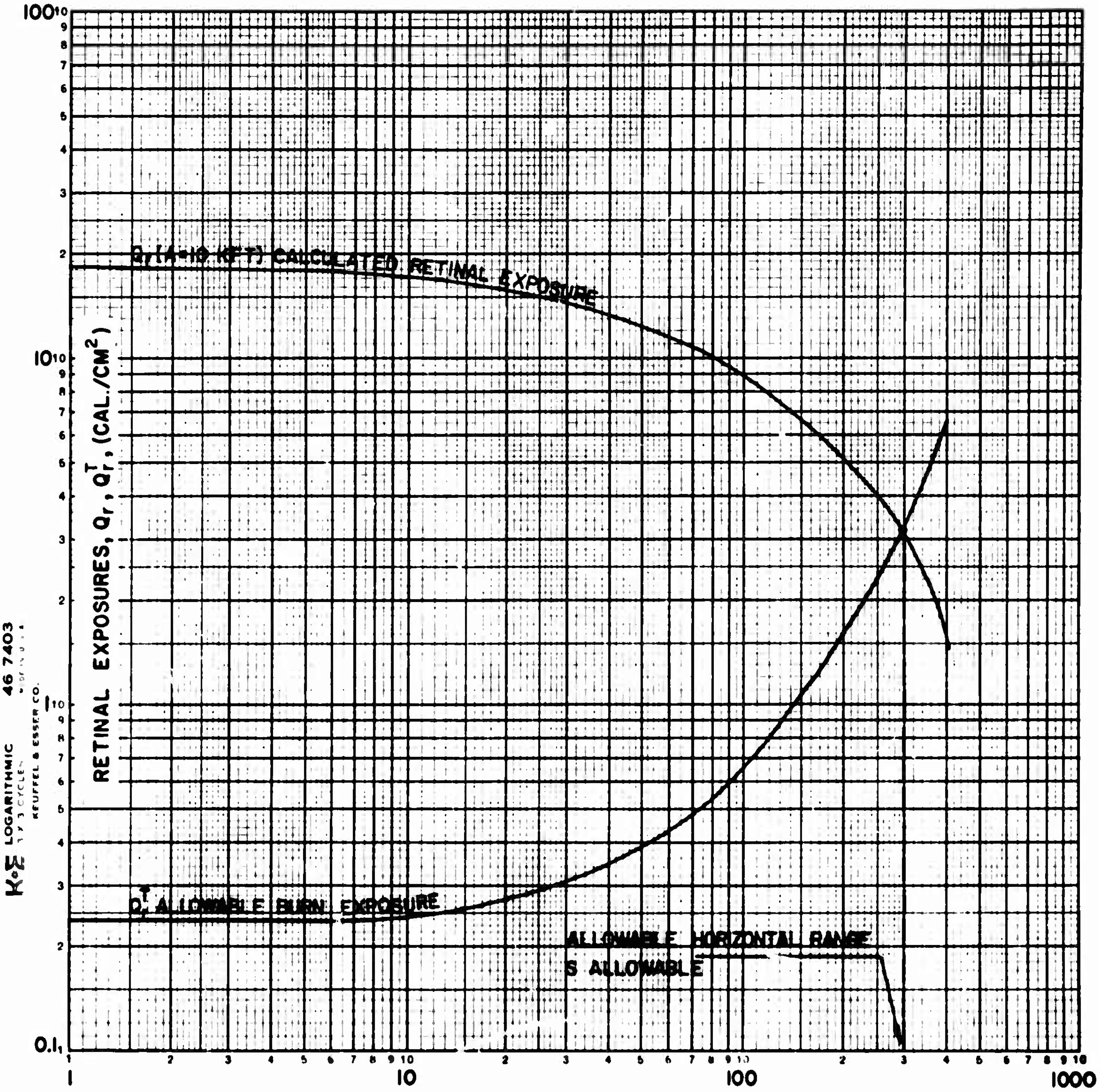


FIGURE 10. Threshold distance determination.

RETINAL BURN

DAY MISSION

YIELD: 2 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	—
D	—

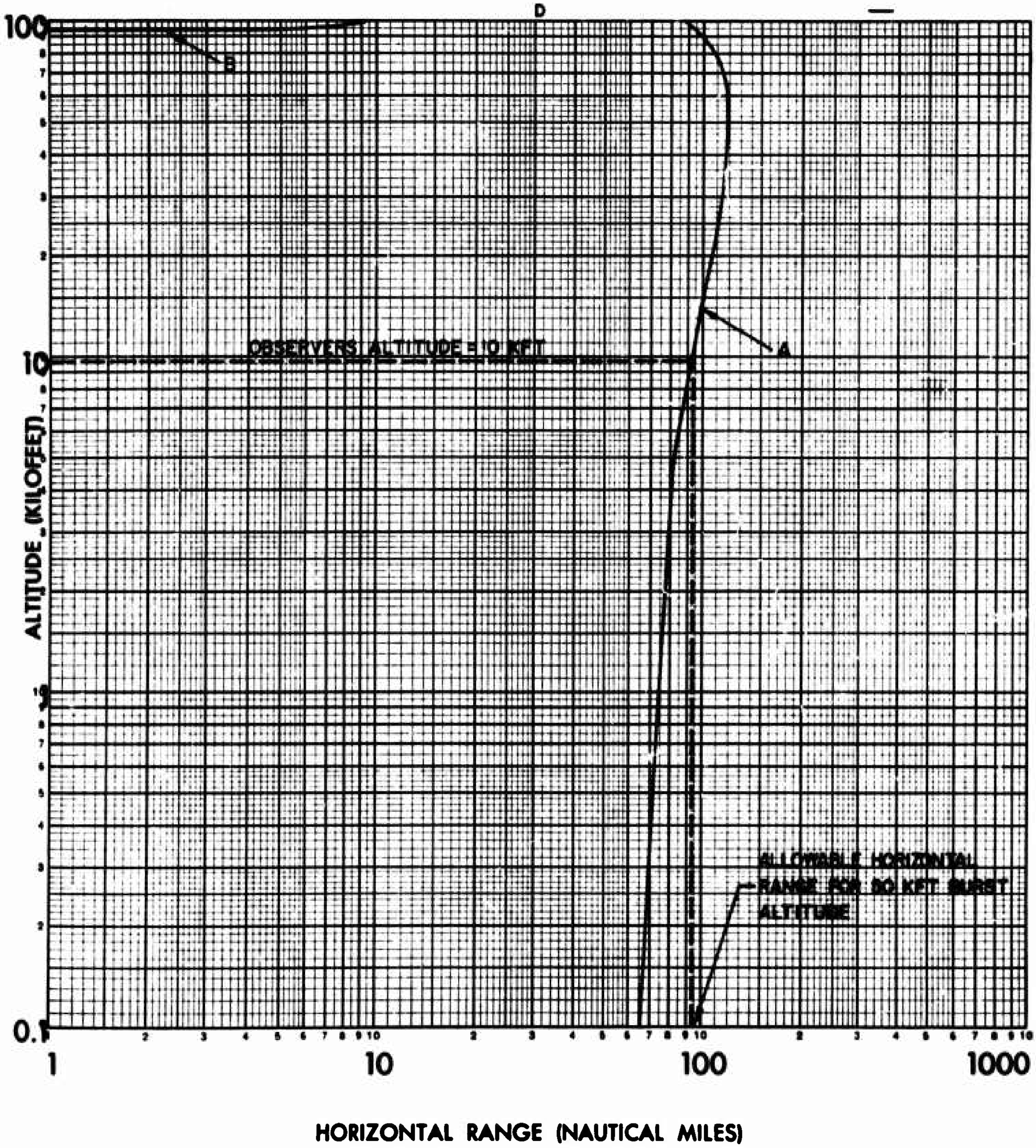


FIGURE 11. Typical retinal burn safe separation envelope.

If the image of the fireball falls directly on the fovea and the image is approximately the size of the macula (or larger), a significant period of flashblindness can result--even though no burn is produced. For this case, calculation of the exposure is accomplished exactly as for retinal burns except that the exposure is expressed in troland-seconds. However, if the fireball subtends an angle less than about three degrees (one millimeter image diameter) it is possible to "look around" the afterimage using the para-fovea area where acuity is still relatively high[10]. Thus, a very small after-image in the macula may be annoying but it does not present a significant decrement in visual acuity. Accordingly, recovery time is computed for a foveal exposure from the direct (unscattered) radiation only when the image of the fireball is equal to or greater than one millimeter. When the image of the fireball is less than one millimeter, it is assumed that the limiting stimulus will be presented to the fovea by diffuse radiation that reaches the retina after being scattered from the air, clouds, ground or water, and by the clear media of the eye itself. Calculation of this component of the luminous energy is in principal much more complex than is the calculation of the direct unscattered radiation that makes up the image. Estimation of the scattered component is accomplished through an adaptation of the method described by Vos[11][12]. Exposures calculated in this way are compared with threshold exposures (for a specified recovery time) determined in laboratory experiments using humans[13]. As before, the condition $E_r = E_r^A$ defines the safe or acceptable separation distance.

According to the procedures discussed above, the curves presented in Figures 13-116, describe distances at which visual acuity will return to 20/120 at the center of the fovea, or at 1-1/2 degrees from the center of the fovea, within 10 seconds under typical cockpit lighting conditions. Figure 12 shows a typical flashblindness envelope.

V. MISSION PLANNING

The charts (Figures 13-116) included in this section can be used to assess the retinal burn and flashblindness hazard in planning nuclear strike missions. It is assumed that, for planning purposes, the following are known:

1) Weapon yield
2) Detonation altitude
3) Observer altitude
4) Day or night detonation

With the charts and this information, allowable separation distances or "danger-zones" can be established. The term "danger-zone" does not mean prohibited zone, but merely that appropriate safety measures should be taken to insure aircrew eye safety while in the zone. Each of the curves has the same format, with altitude given in thousands of feet and horizontal range given in nautical miles. Figures 11 and 12 illustrate the use of the retinal burn and flashblindness charts in determining allowable separation distances. The steps to be followed in using a chart are outlined below:

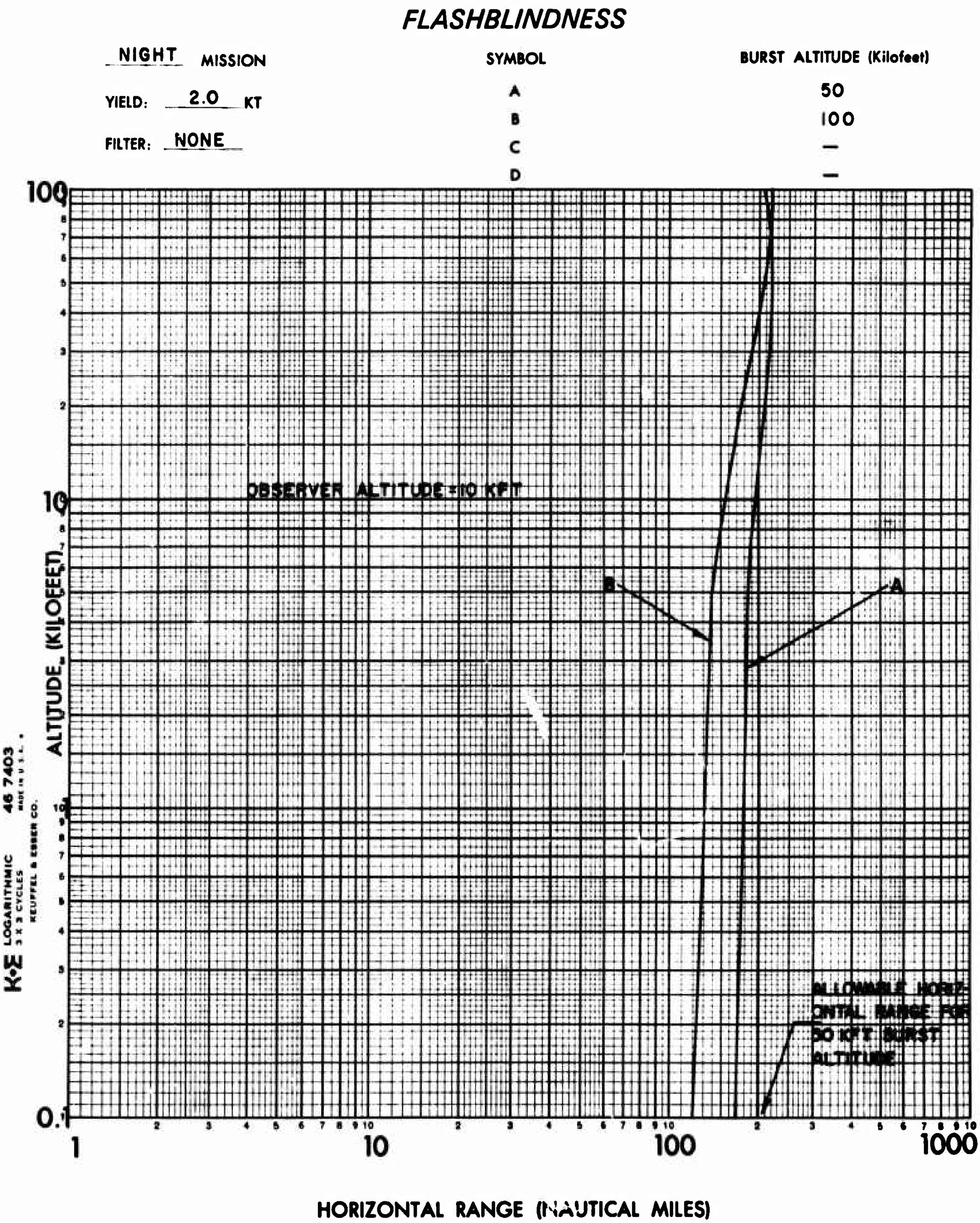


FIGURE 12. Typical flashblindness safe separation envelope.

1) Select the set of "day" or "night" curves for the weapon yield under consideration. Each curve applies to a particular burst altitude as noted in the legend. Identify the curve which represents the desired burst altitude.

2) Select the observer altitude on the ordinate and follow this altitude horizontally to its intersection with the envelope curve.

3) The abscissa of the point of intersection is then the allowable separation distance. This value can be used directly on a map, or the slant range can be calculated as follows:

$$\text{Slant Range (Naut. Miles)} = \left[(\text{Horiz. Range})^2 + \left(\frac{\text{Obs. Alt. - Burst Alt.}}{6.08}\right)^2\right]^{1/2}$$

Where Horizontal Range is in nautical miles and both Observer Altitude and Burst Altitude are in kilofeet.

Safe separation envelopes have been calculated for detonations during daylight (with and without a 2% gold visor for protection) and for night detonations. The protection afforded by the gold visor is sufficient to eliminate the hazard of retinal burns for day exposures for all of the situations considered, therefore, no envelopes are presented for this combination of conditions.

It should be emphasized that the "safe separation" distances presented here pertain only to retinal burns or flashblindness and are specific to the exposure conditions assumed, e.g. 0.25 second or 0.45 second blink time, 2.5 mm or

6.5 mm pupil diameter, etc. If an allowable distance for flashblindness is less than an allowable retinal burn distance, the conclusion is simply that retinal burns present the limiting approach distance insofar as these two phenomena are concerned. It may be that in some instances the blast, thermal, or radiation hazard extends to a greater distance than either the flashblindness or retinal burn hazard. In this case, the allowable approach distance is not determined by retinal burns or flashblindness.

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12. Vos, J. J. Temporary and permanent loss of visual functions by flashes at nuclear explosions. A theoretical approach. Report No. 1959-7, Institute for Perception RVO-TNO, 1959. (DDC Cat. No. AD 332 591) Confidential.

13. Miller, N. D. Visual recovery from high intensity flashes. Annual Phase Report, USAF Contract AF 41(609)-2426, July 1965.

RETINAL BURN AND FLASHBLINDNESS SAFE SEPARATION ENVELOPES

FIGURES 13-116

RETINAL BURN SAFE SEPARATION ENVELOPES

DAY MISSION

RETINAL BURN

DAY MISSION

YIELD: 0.02 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	10
C	25
D	50

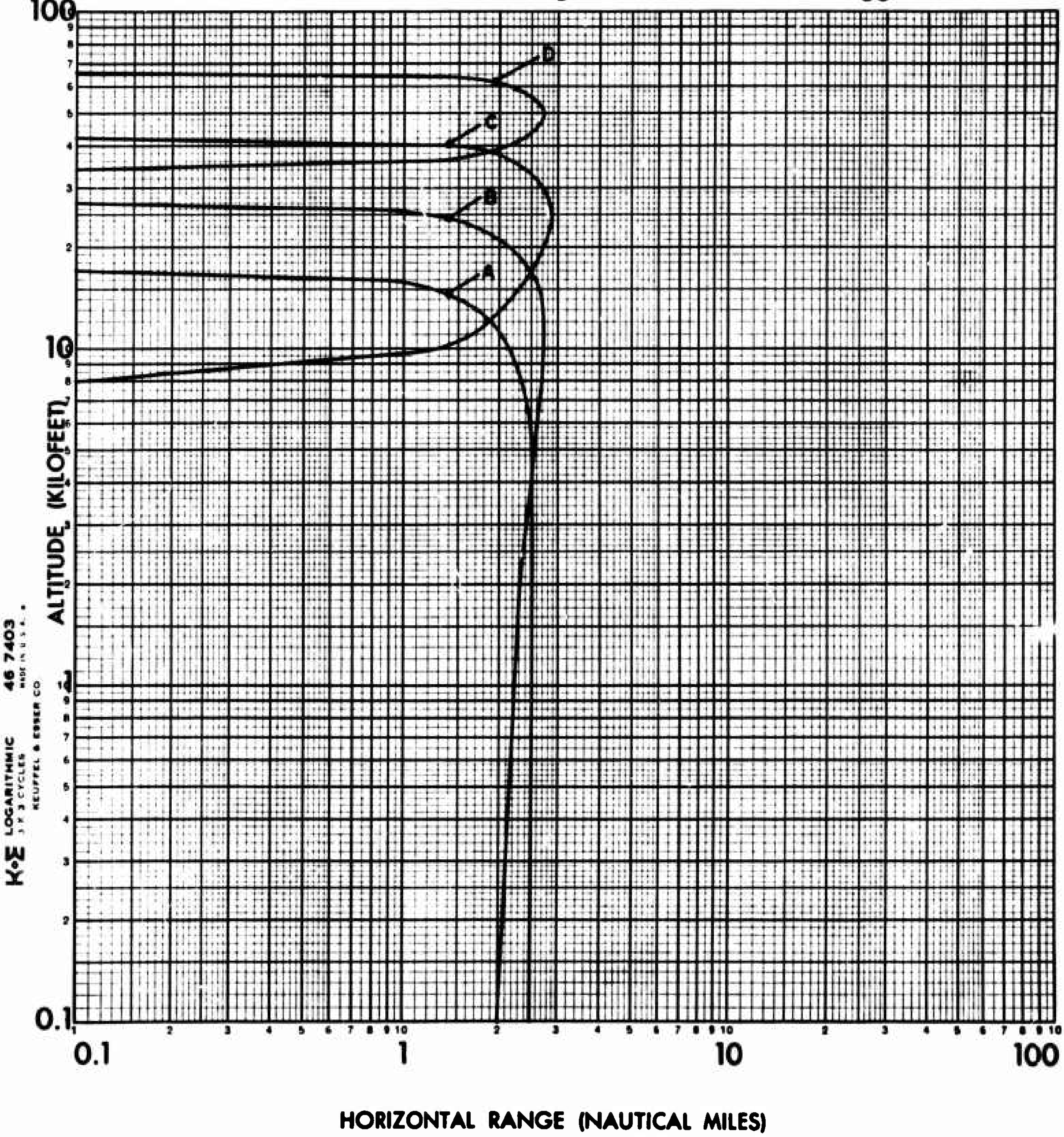


FIGURE 13

RETINAL BURN

DAY MISSION

YIELD: 0.02 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	75
B	—
C	—
D	—

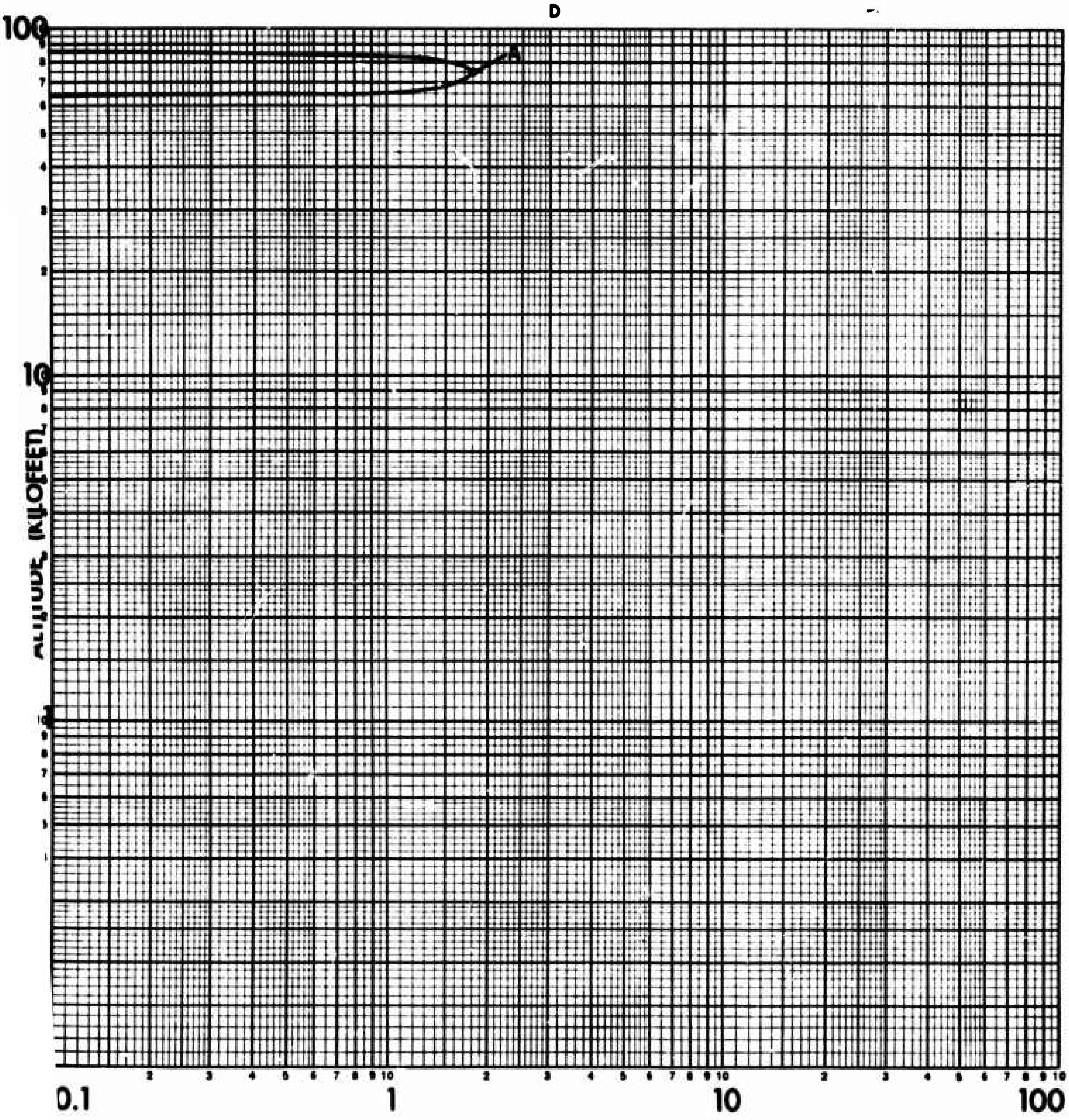


FIGURE 14

No Retinal Burn Envelope Exists for the Following Conditions:

DAY MISSION

W = 0.02 KT

HB = 100 KFT

FILTER: NONE

FIGURE 15

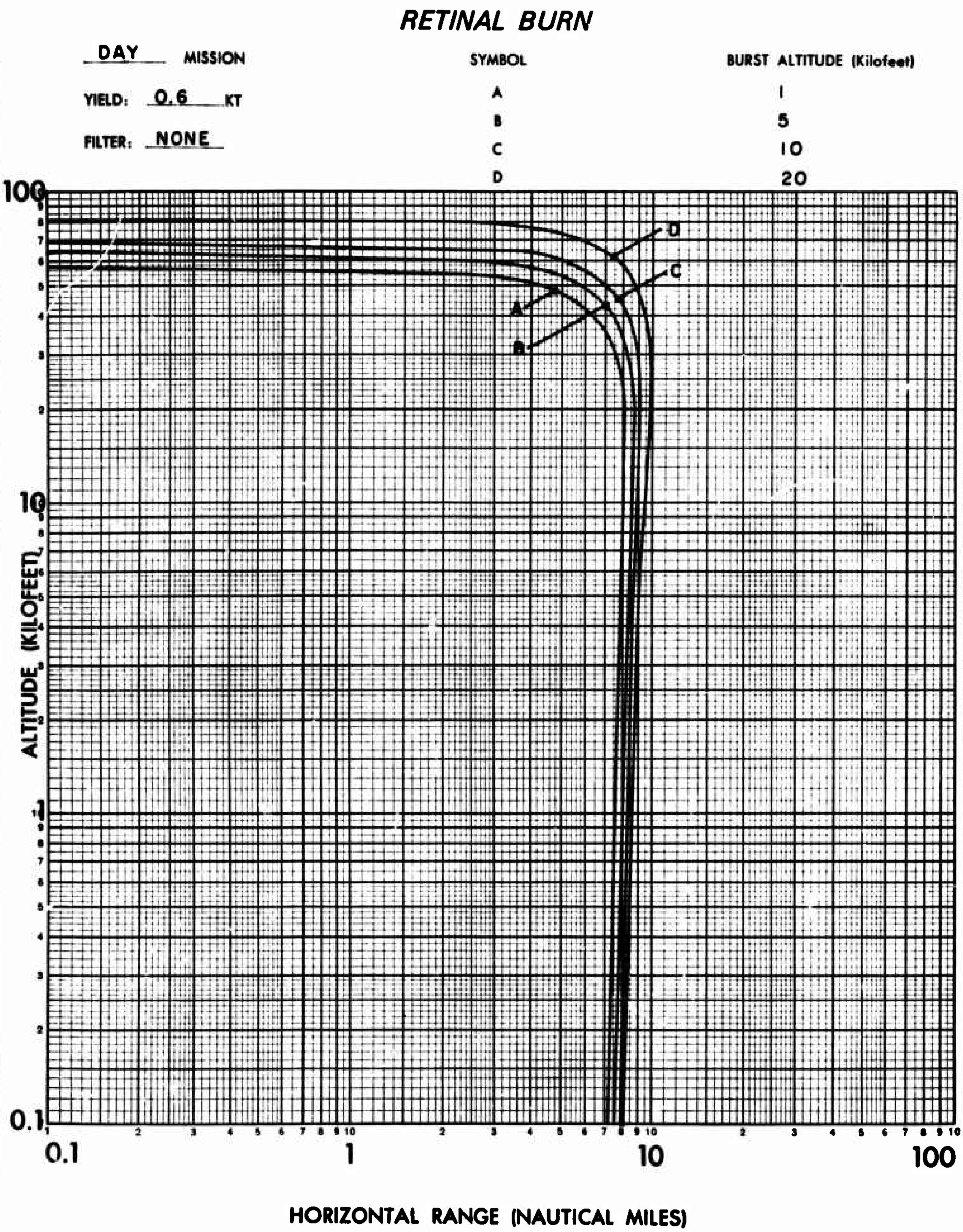

RETINAL BURN
DAY MISSION
YIELD: 0.6 KT
FILTER: NONE
SYMBOL
BURST ALTITUDE (Kilofeet)
A 1
B 5
C 10
D 20
A
B
C
D
100
10
1
0.1
ALTITUDE (KILOFEET)
0.1
1
10
100
HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 16

RETINAL BURN

DAY MISSION		SYMBOL	BURST ALTITUDE (Kilofeet)
YIELD: 0.6 KT		A	50
FILTER: NONE		B	100
		C	–
		D	–

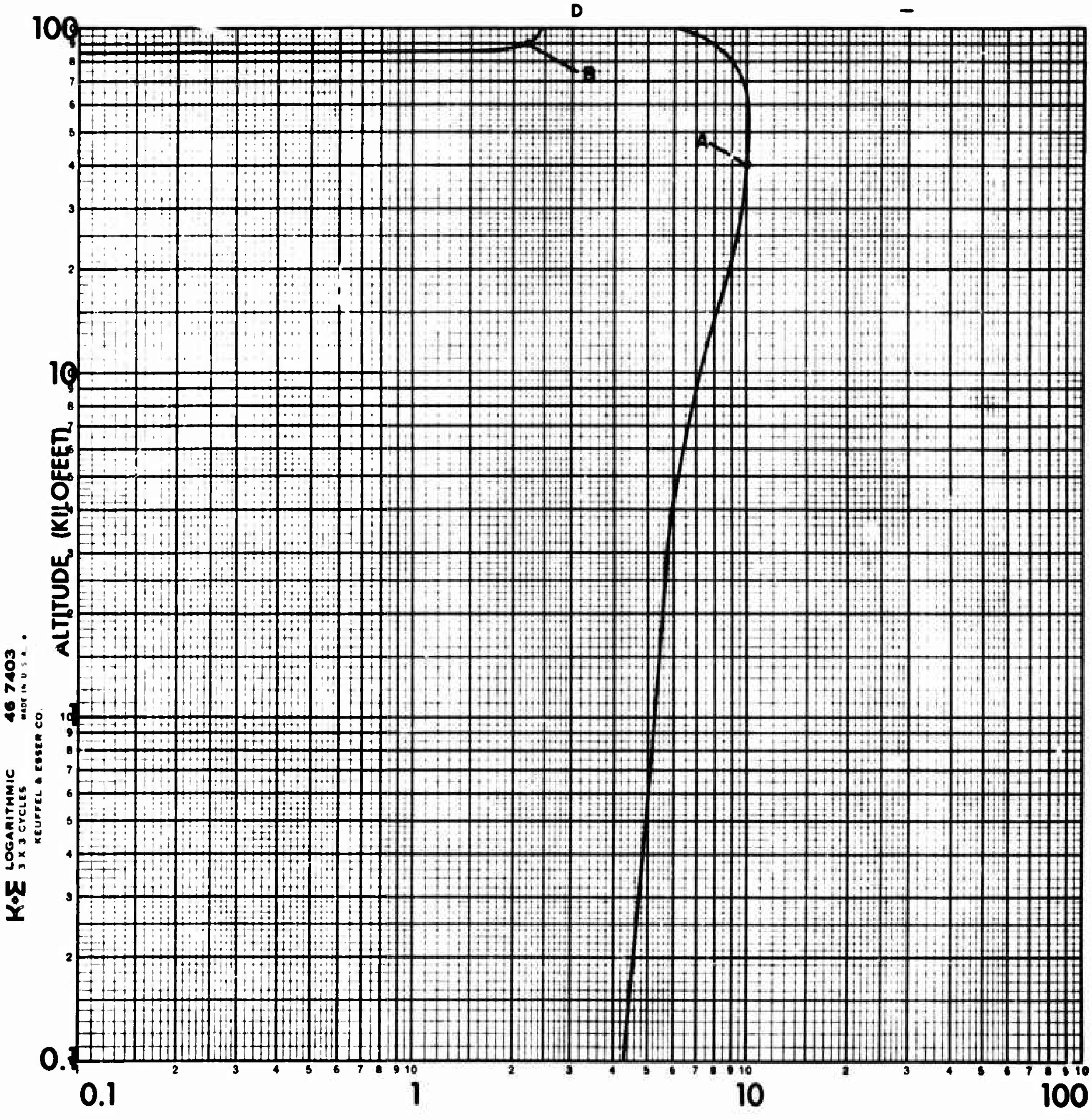


FIGURE 17

RETINAL BURN

DAY MISSION

YIELD: 2.0 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	5
C	10
D	20

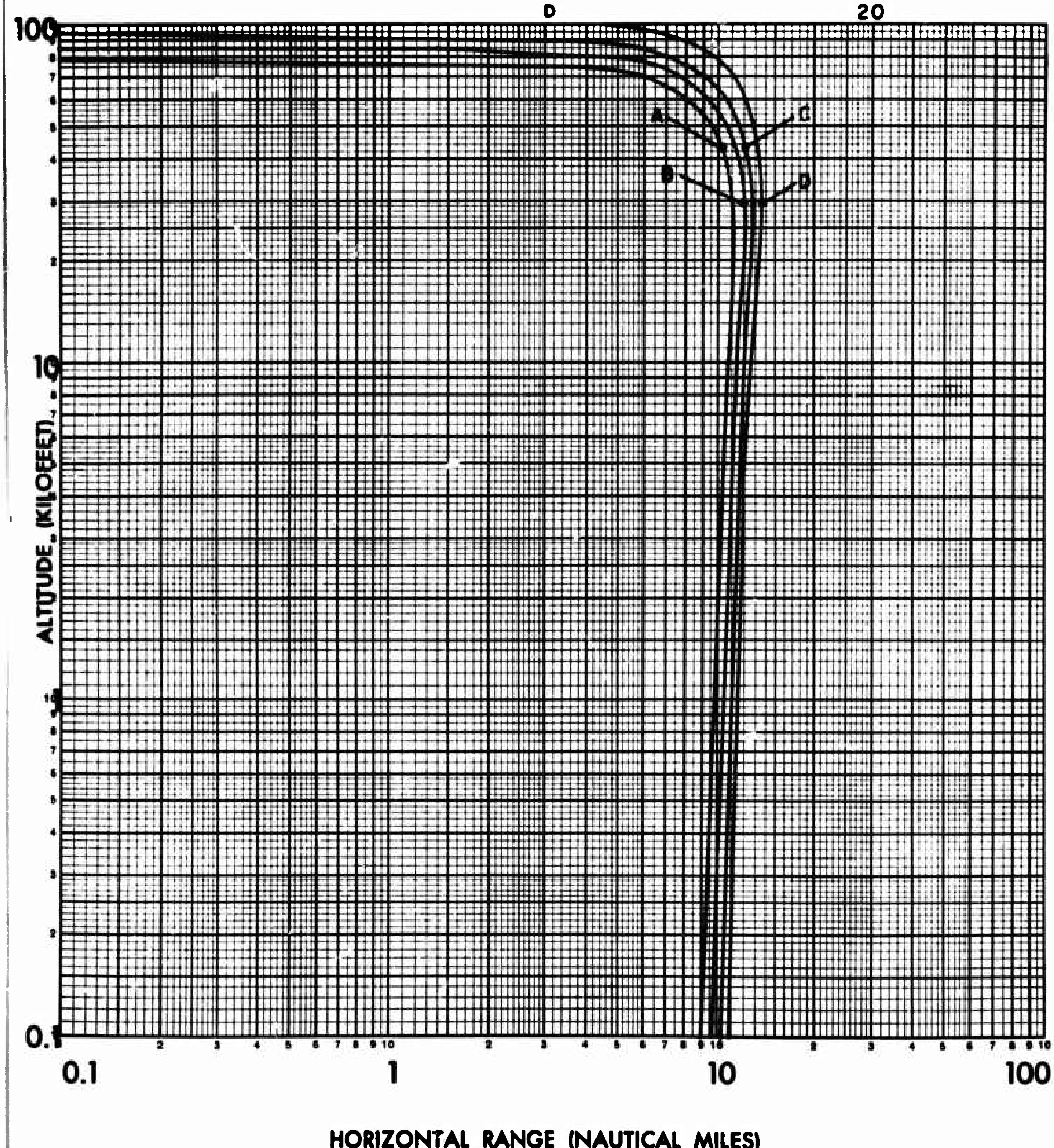


FIGURE 18

RETINAL BURN

DAY MISSION

YIELD: 2 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	—
D	—

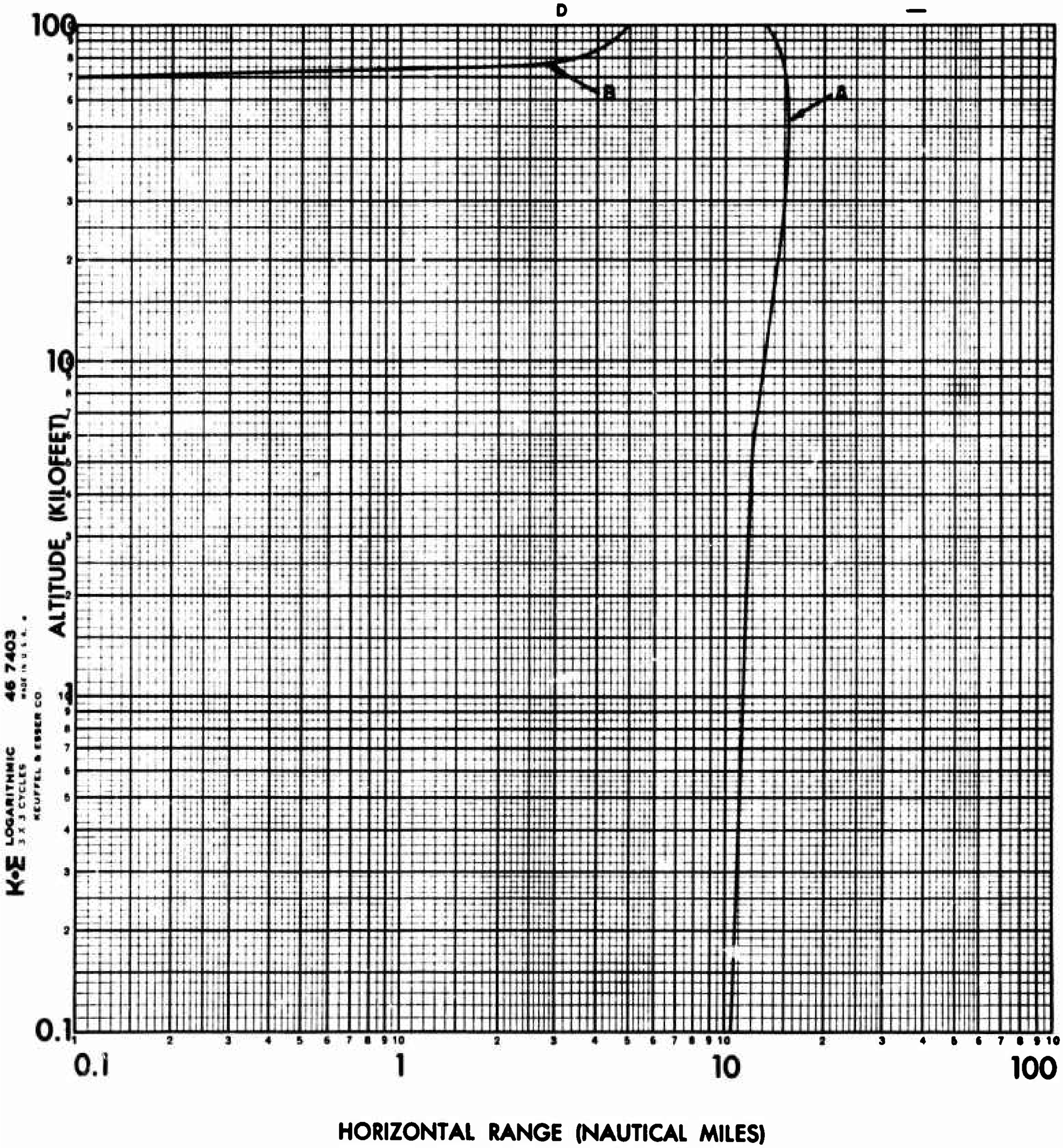


FIGURE 19

RETINAL BURN

DAY MISSION

YIELD: 10 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	5
C	10
D	20

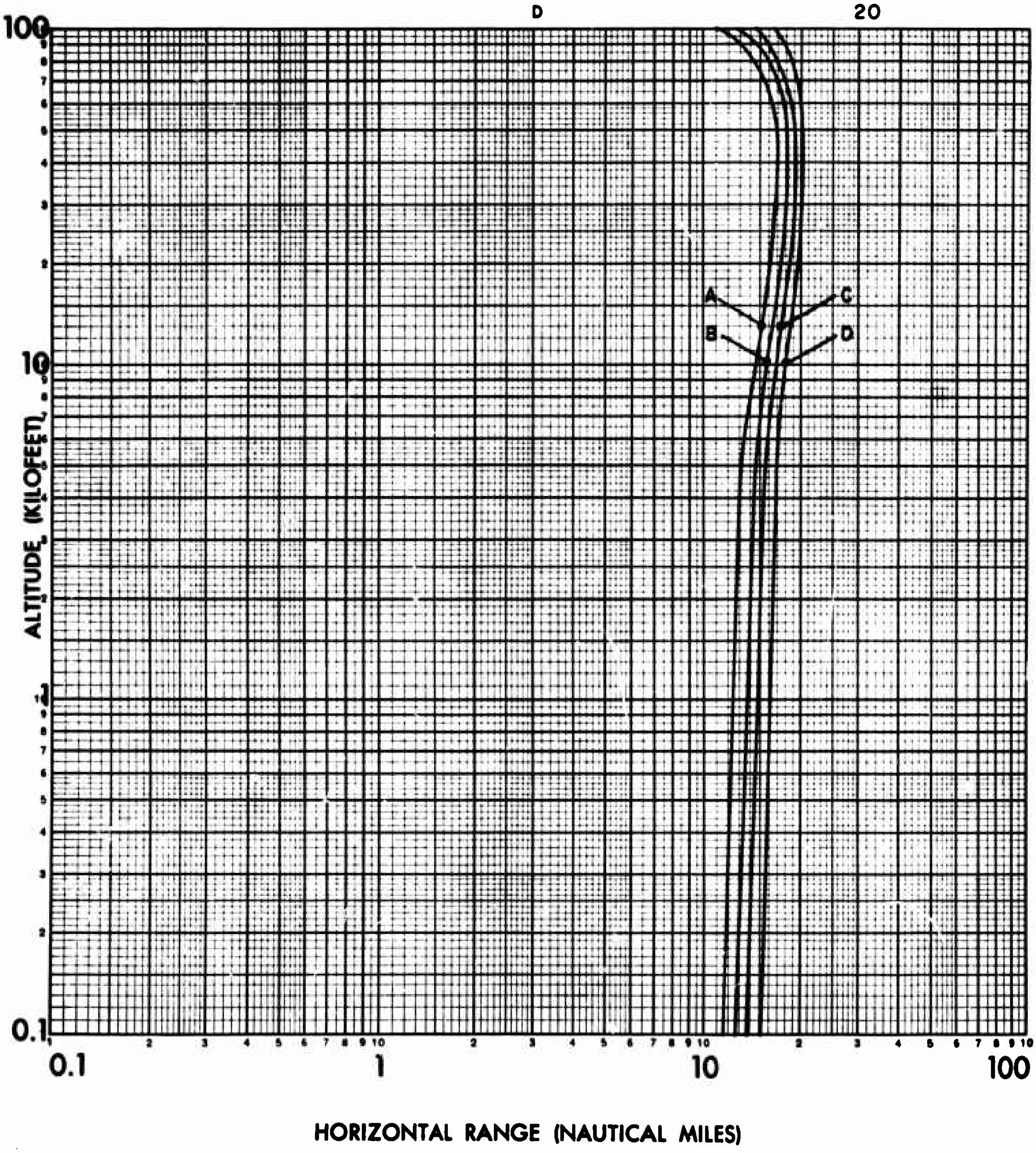


FIGURE 20

RETINAL BURN

DAY MISSION

YIELD: 10 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	–
D	–

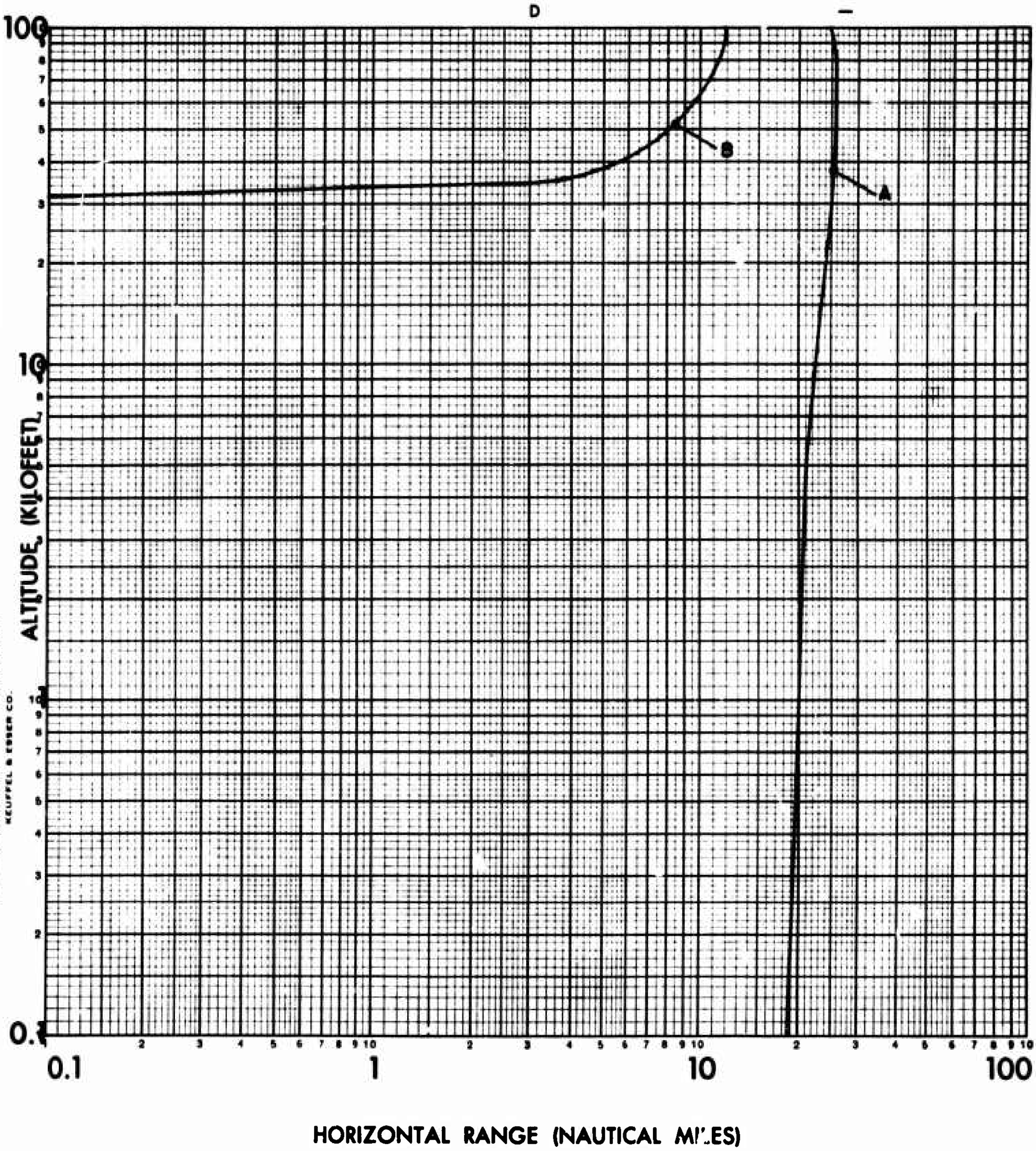


FIGURE 21

RETINAL BURN

DAY MISSION

YIELD: 30 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	5
C	10
D	20

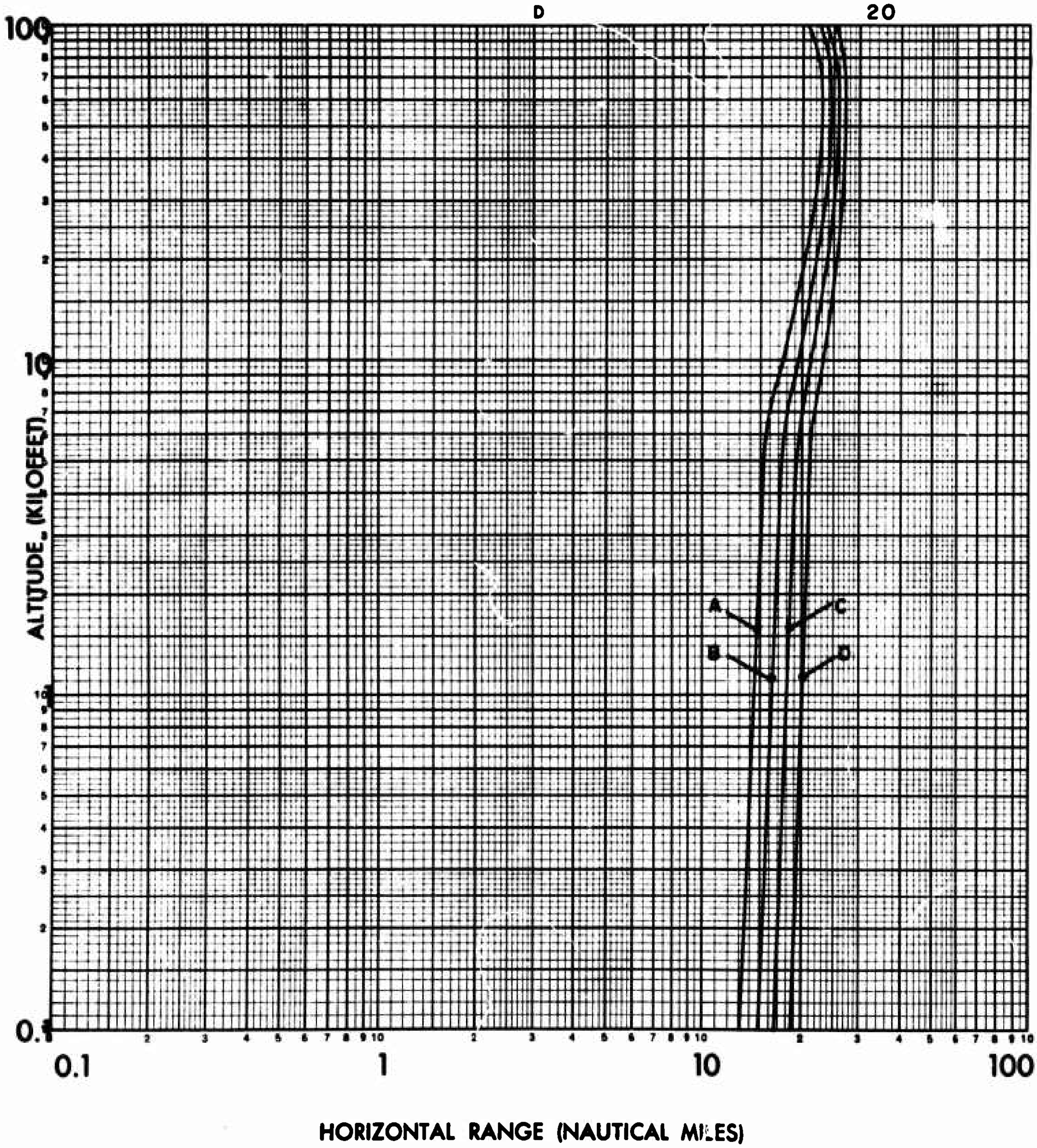


FIGURE 22

RETINAL BURN

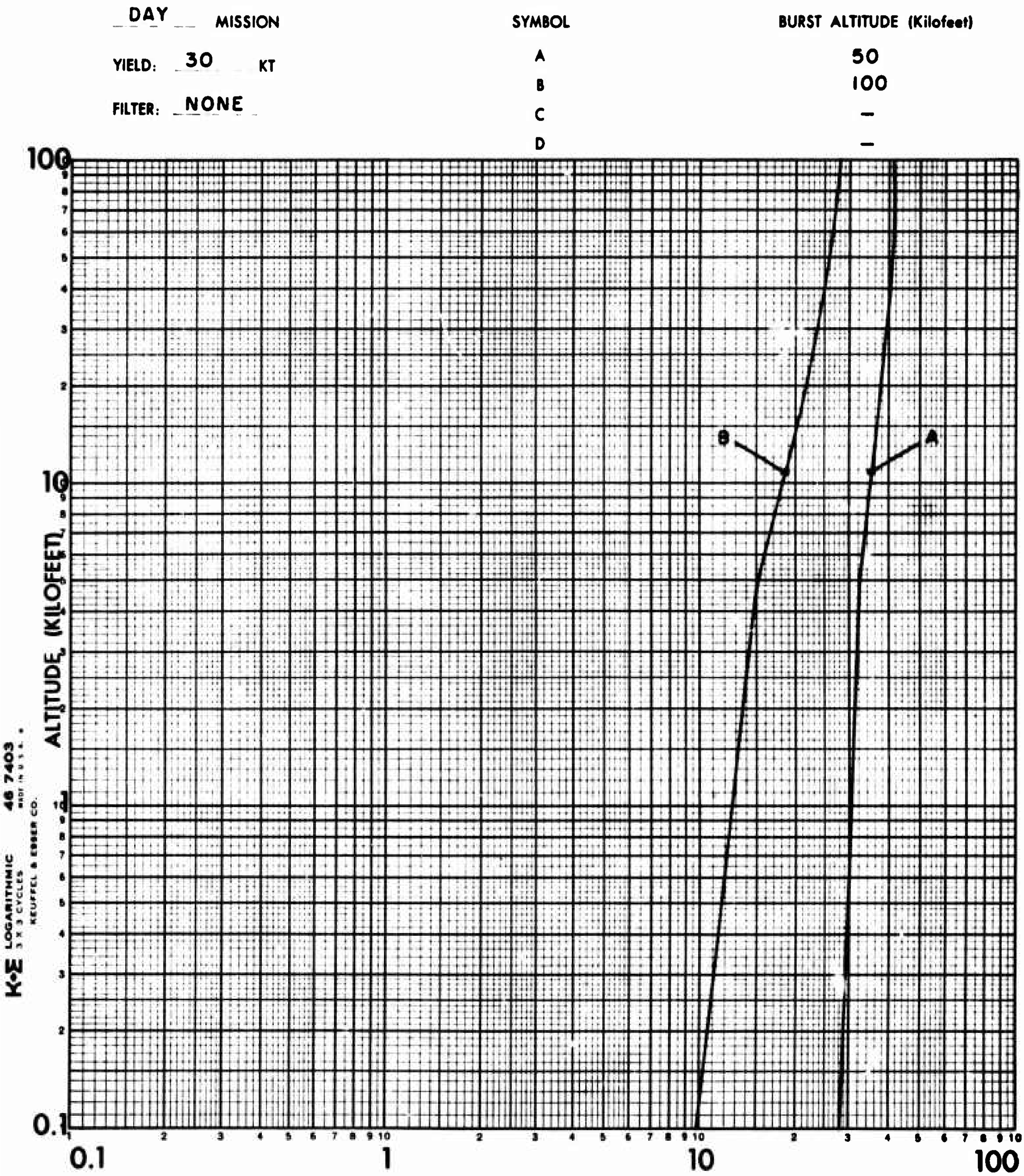


FIGURE 23

RETINAL BURN

DAY MISSION

YIELD: 60 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	5
C	10
D	20

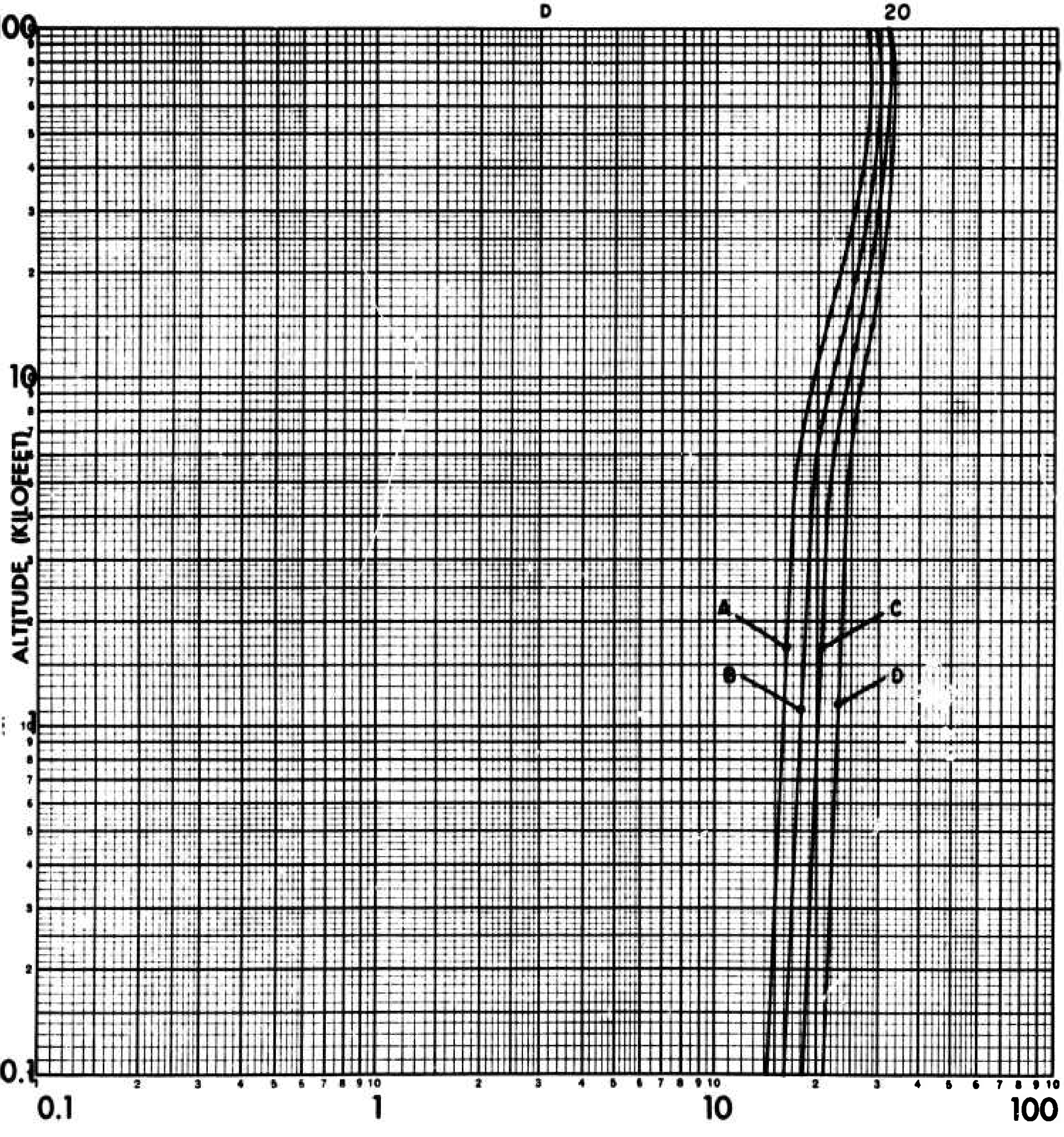


FIGURE 24

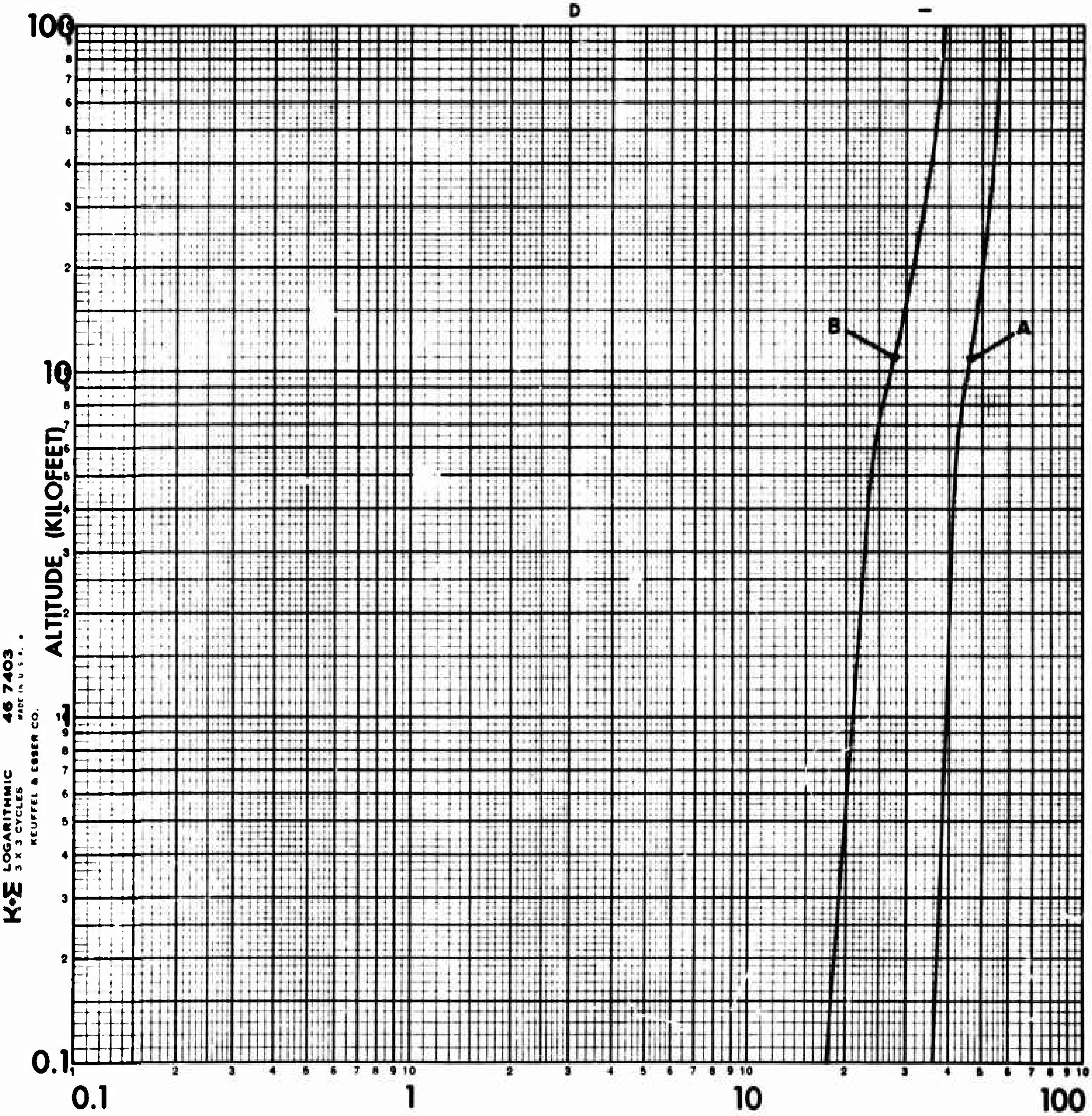
RETINAL BURN

DAY MISSION

YIELD: 60 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	–
D	–



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 25

RETINAL BURN

DAY MISSION

YIELD: 200 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1.5
B	5.0
C	10.0
D	20.0

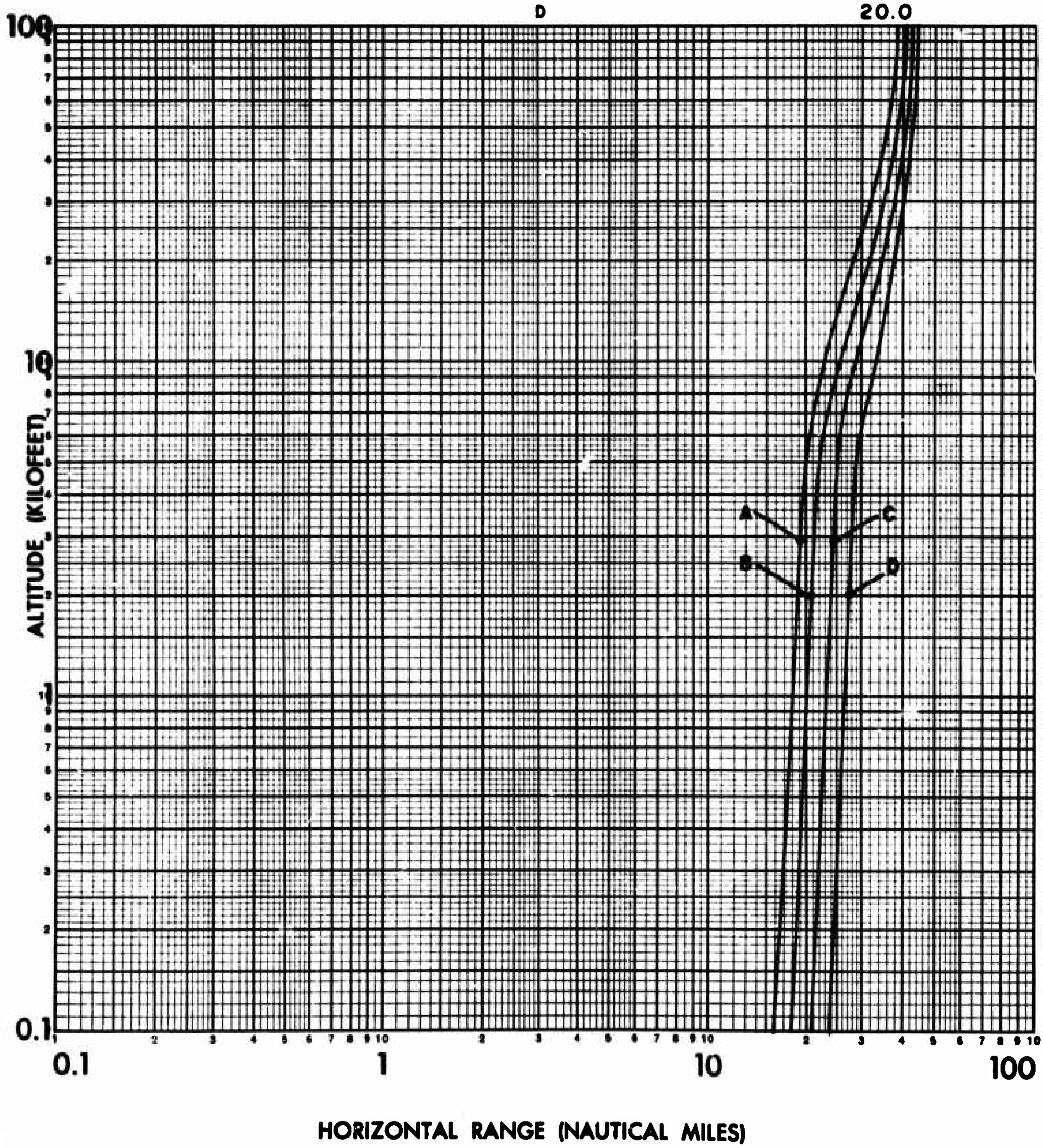


FIGURE 26

RETINAL BURN

DAY MISSION	SYMBOL	BURST ALTITUDE (Kilofeet)
YIELD: 200 KT	A	50
FILTER: NONE	B	100
	C	–
	D	–

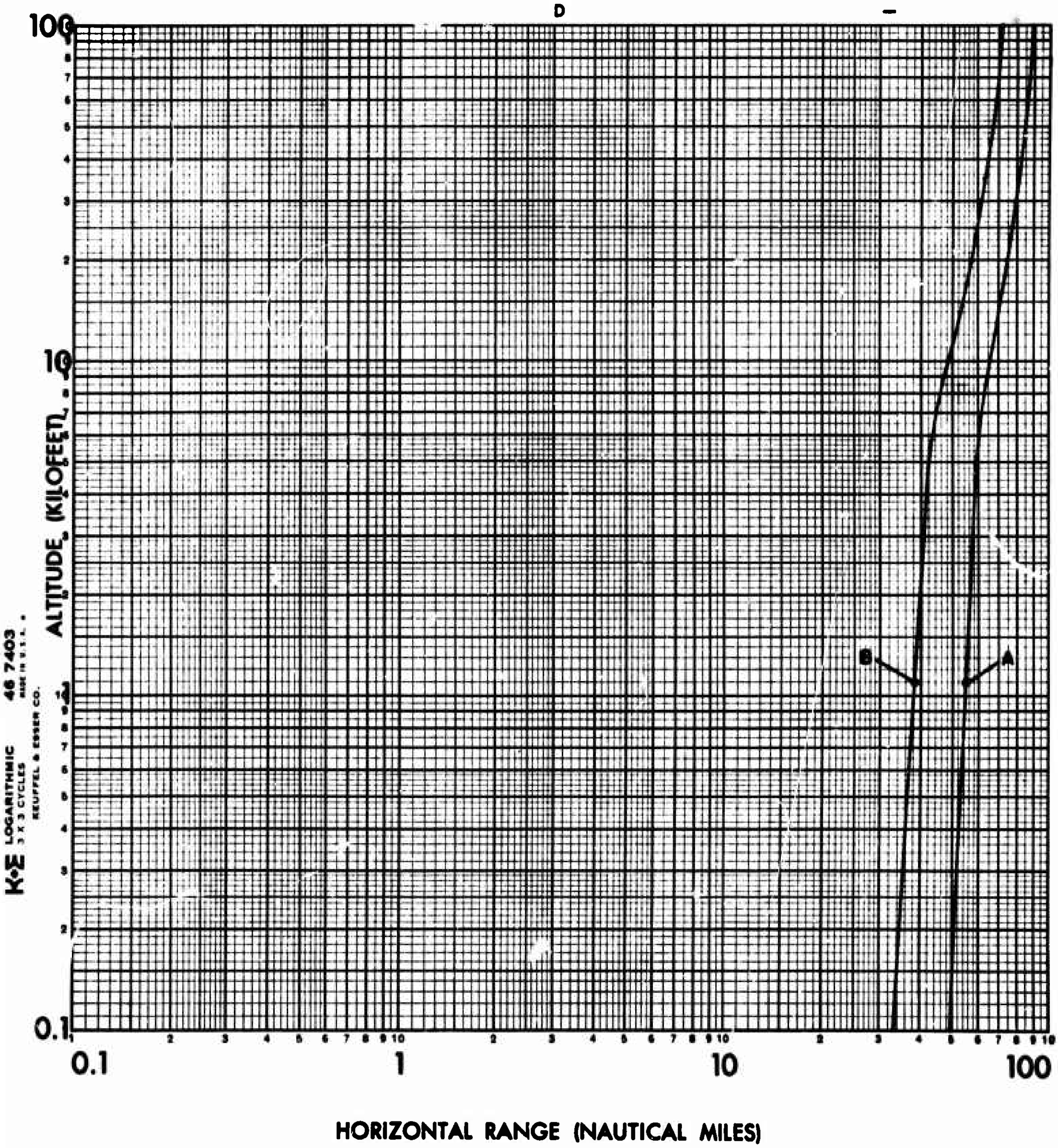


FIGURE 27

RETINAL BURN

DAY MISSION

YIELD: 440 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1.5
B	5
C	10
D	20

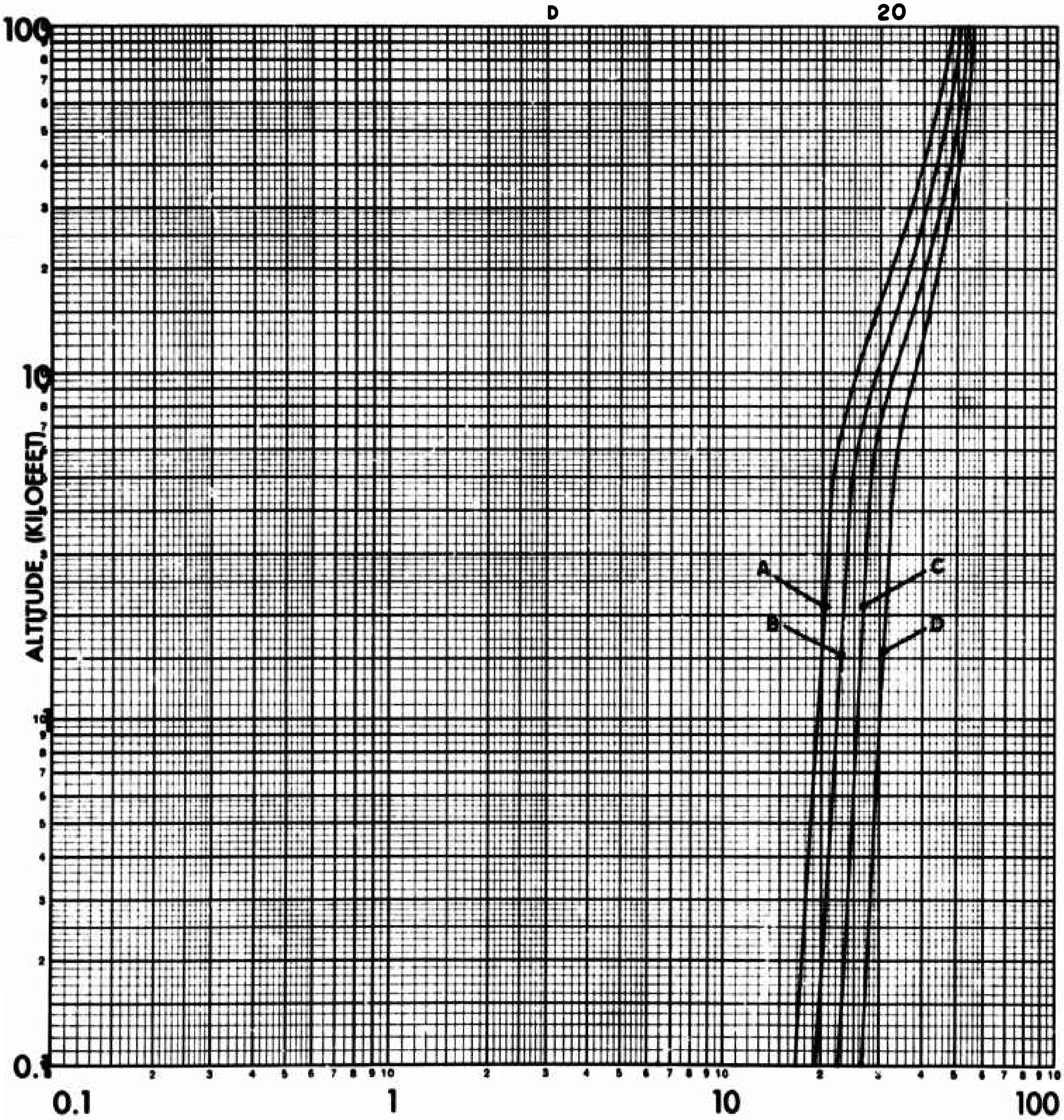


FIGURE 28

RETINAL BURN

DAY MISSION

YIELD: 440 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	–
D	–

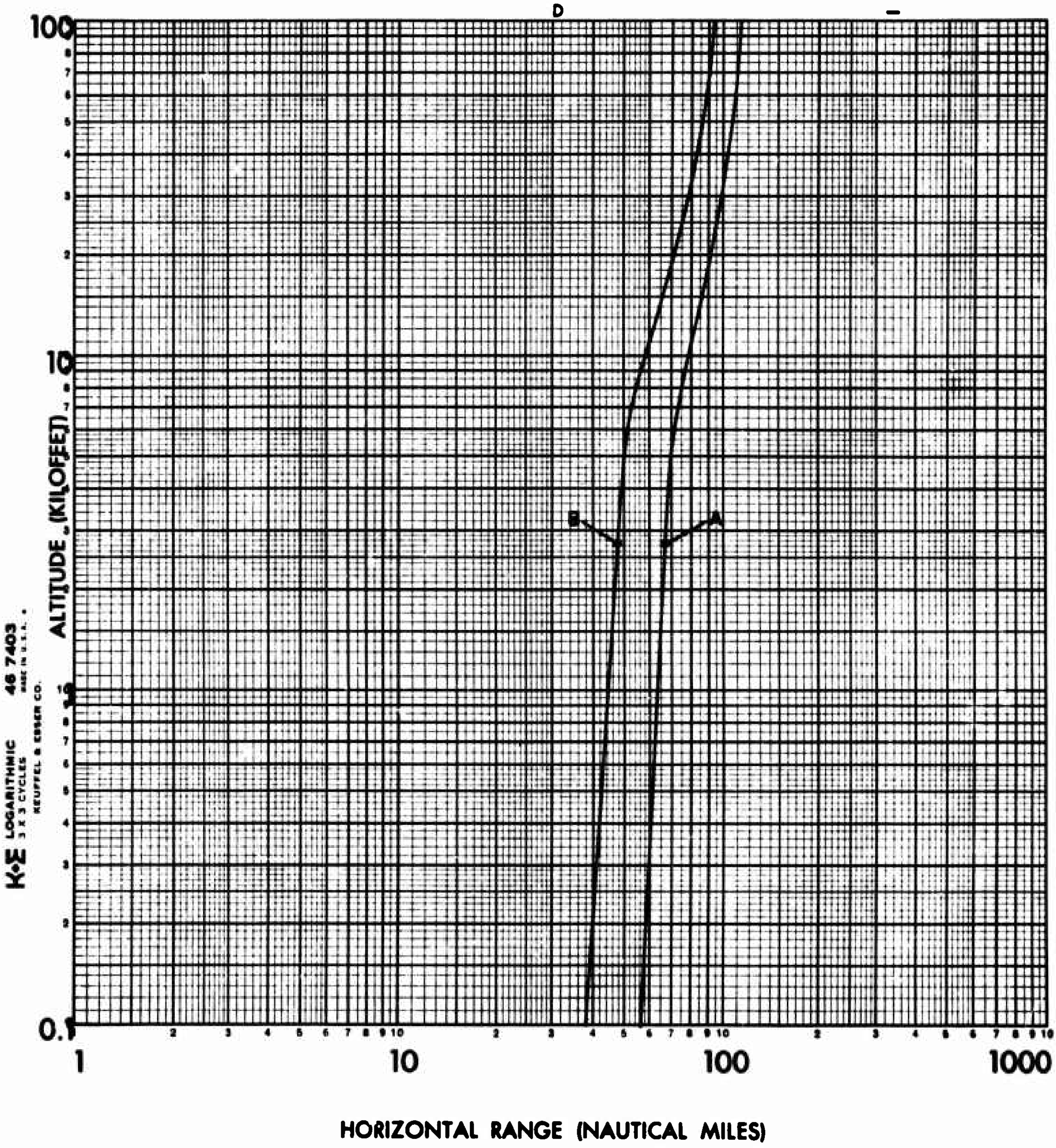


FIGURE 29

RETINAL BURN

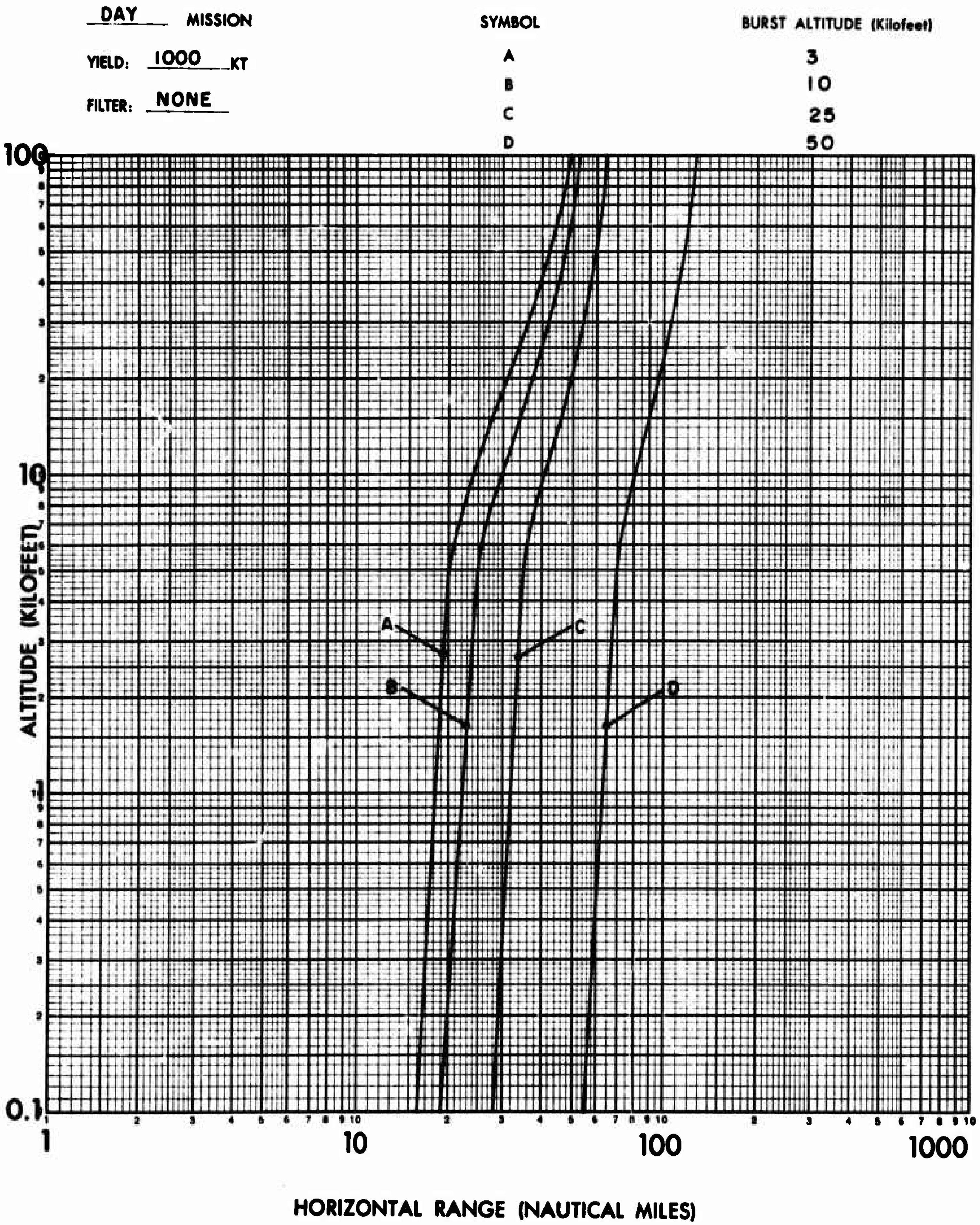


FIGURE 30

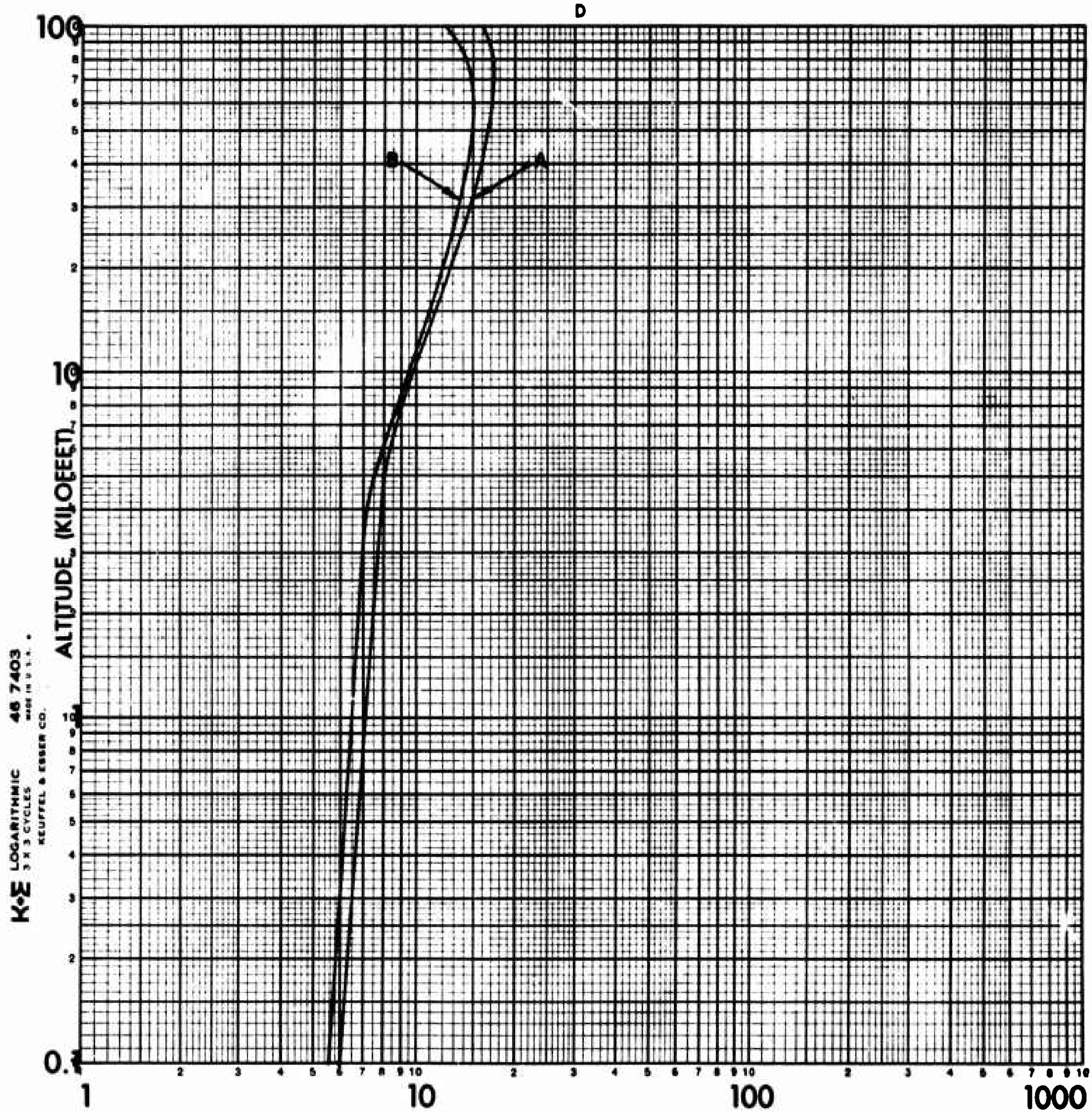
RETINAL BURN

DAY MISSION

YIELD: 3800 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	4
B	10
C	
D	



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 31

RETINAL BURN

DAY MISSION

YIELD: 3800 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	25
B	50
C	–
D	–

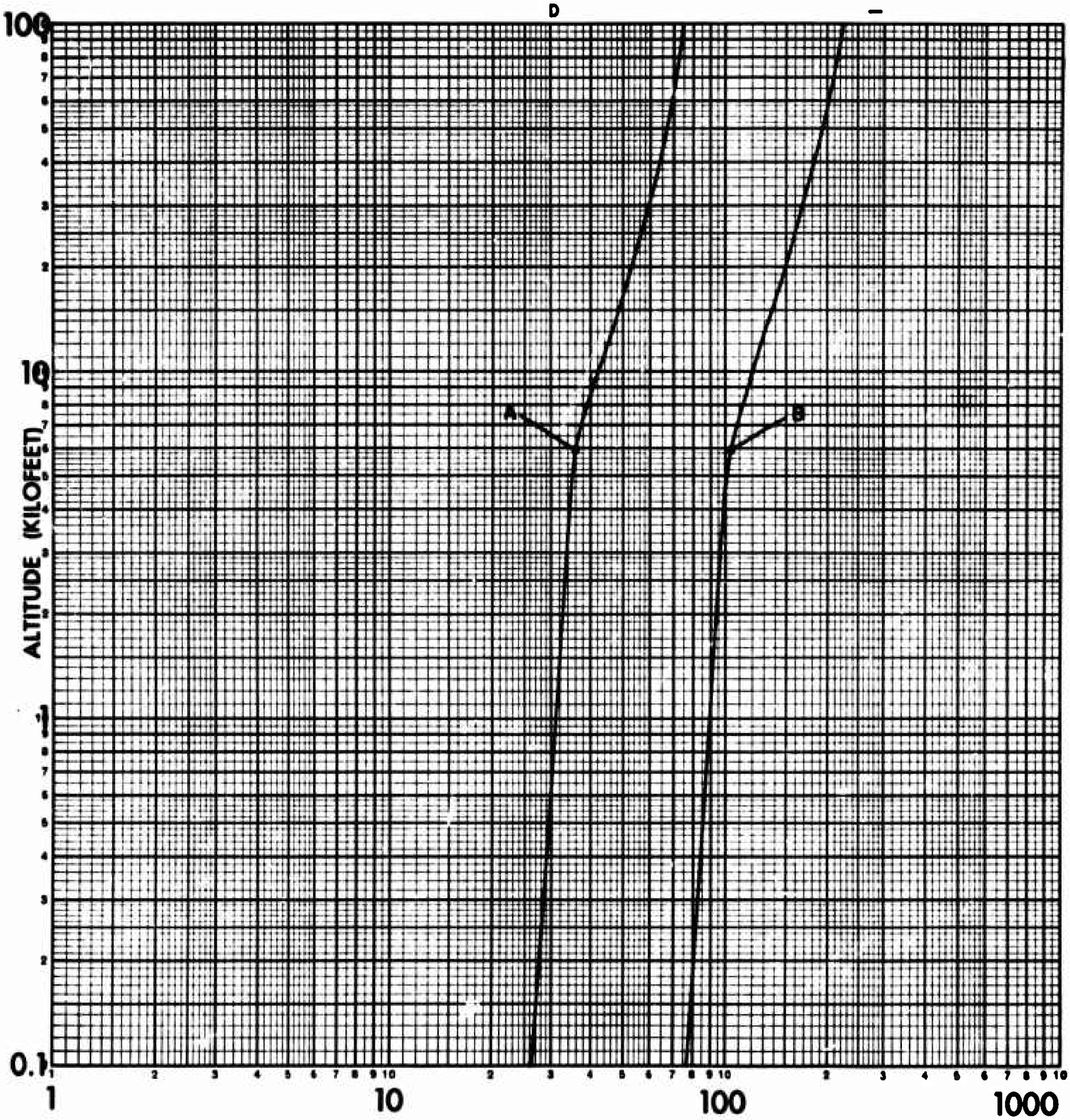


FIGURE 32

No Retinal Burn Envelope Exists for the Following Conditions:

DAY MISSION

W = 9000 KT

HB = 5 KFT and 10 KFT

FILTER: NONE

FIGURE 33

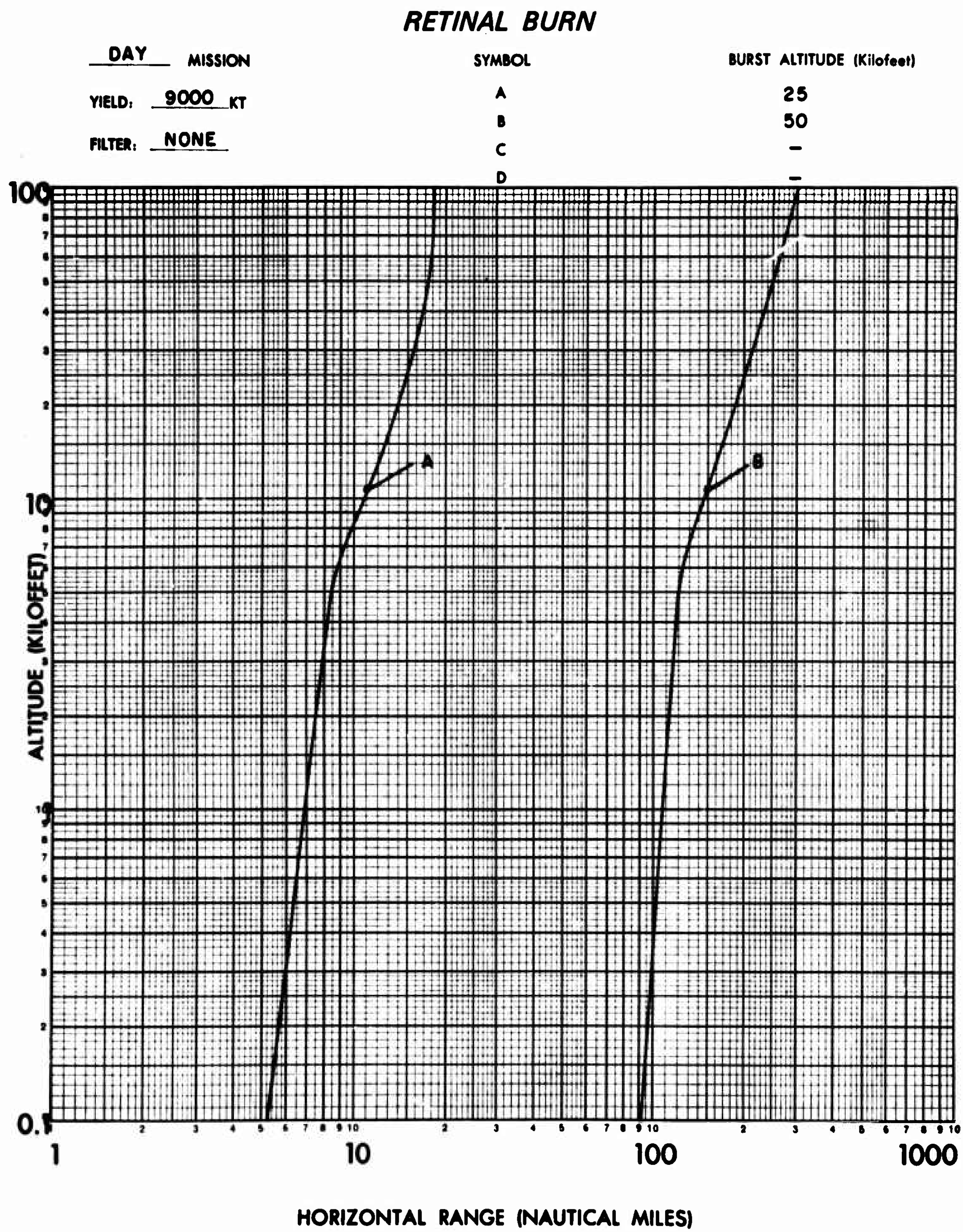

RETINAL BURN
DAY MISSION
YIELD: 9000 KT
FILTER: NONE
SYMBOL
A
B
C
D
BURST ALTITUDE (Kilofeet)
25
50
-
-
ALTITUDE (KILOFEET)
100
10
0.1
1
10
100
1000
A
B
HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 34

RETINAL BURN

DAY MISSION

YIELD: 23000 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	6.
B	25
C	50
D	–

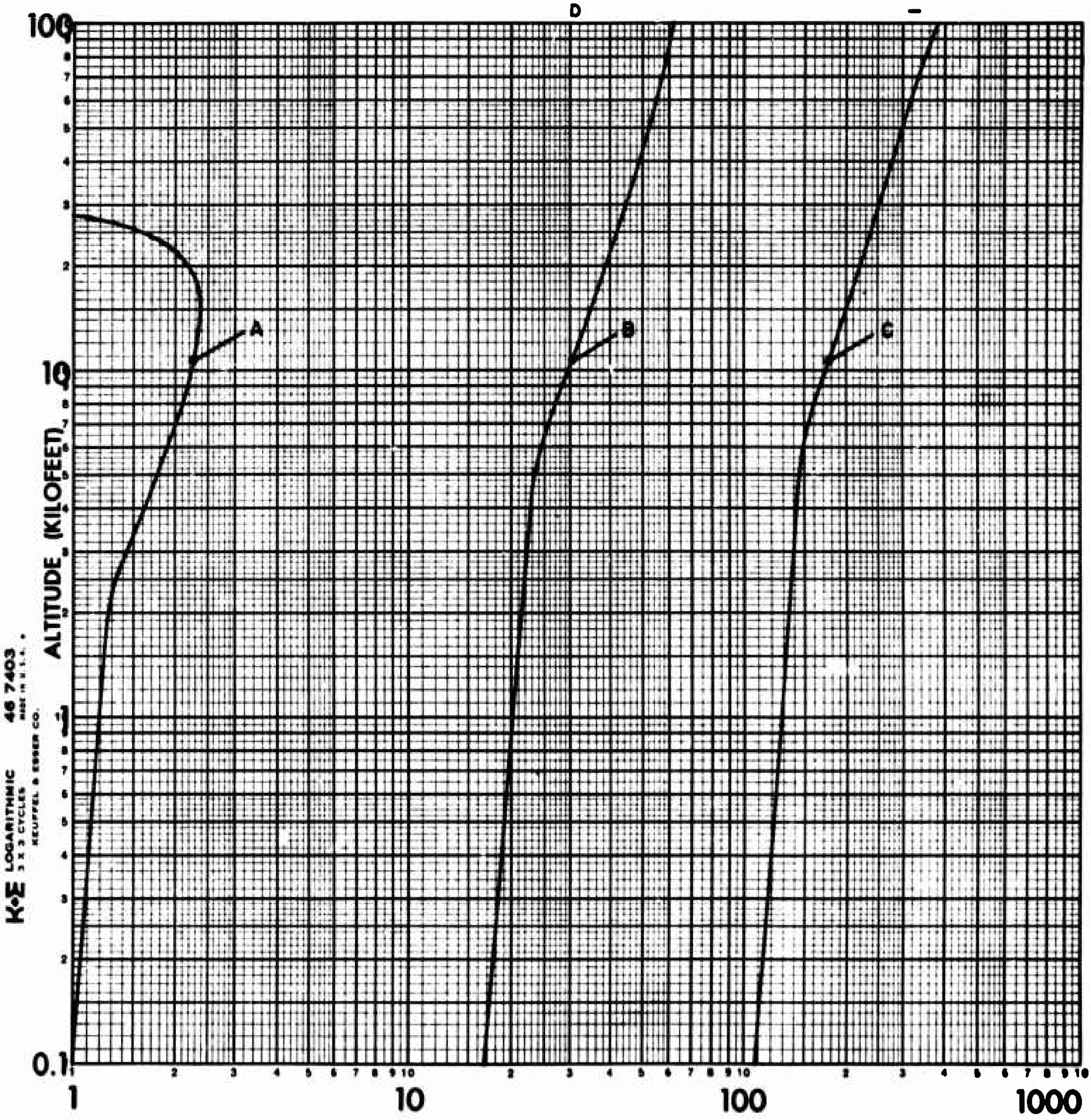


FIGURE 35

No Retinal Burn Envelope Exists for the Following Conditions:

DAY MISSION

W = 23000 KT

HB = 10 KFT

FILTER: NONE

FIGURE 36

RETINAL BURN SAFE SEPARATION ENVELOPES

NIGHT MISSION

RETINAL BURN

NIGHT MISSION

YIELD: 0.02 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	10
C	25
D	50

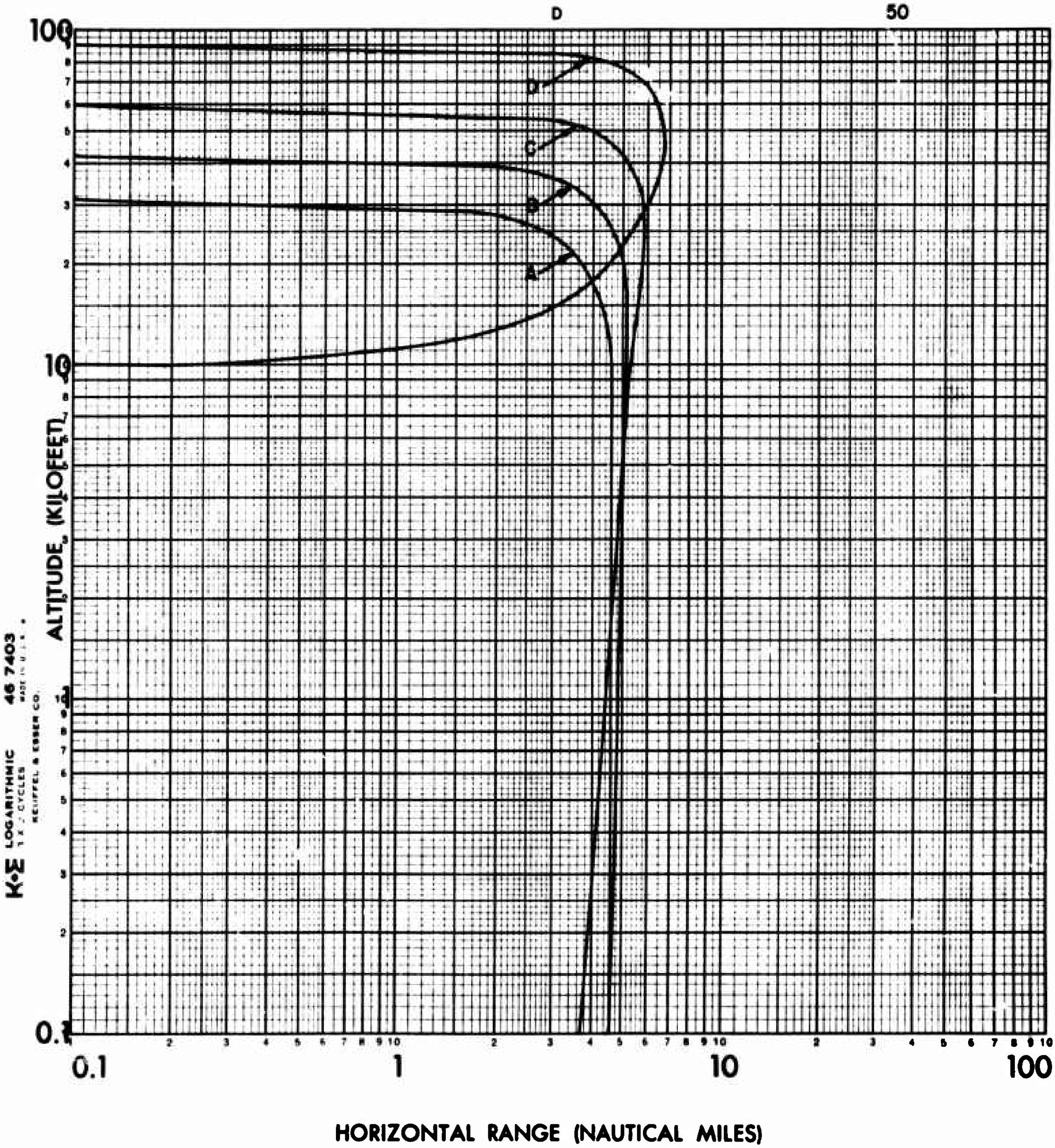


FIGURE 37

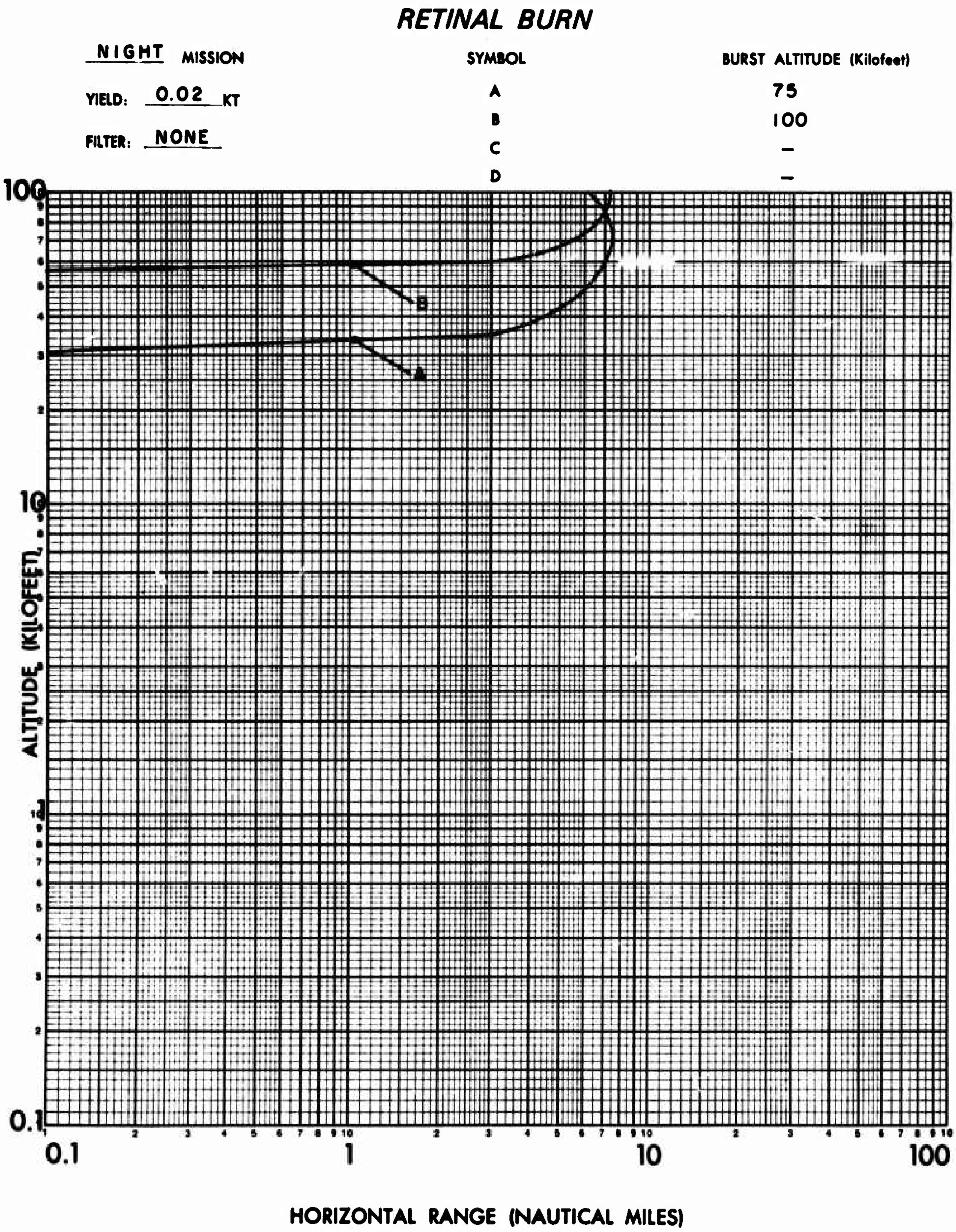

RETINAL BURN
NIGHT MISSION
YIELD: 0.02 KT
FILTER: NONE
SYMBOL
BURST ALTITUDE (Kilofeet)
A 75
B 100
C –
D –
ALTITUDE (KILOFEET)
100
10
1
0.1
B
A
0.1
1
10
100
HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 38

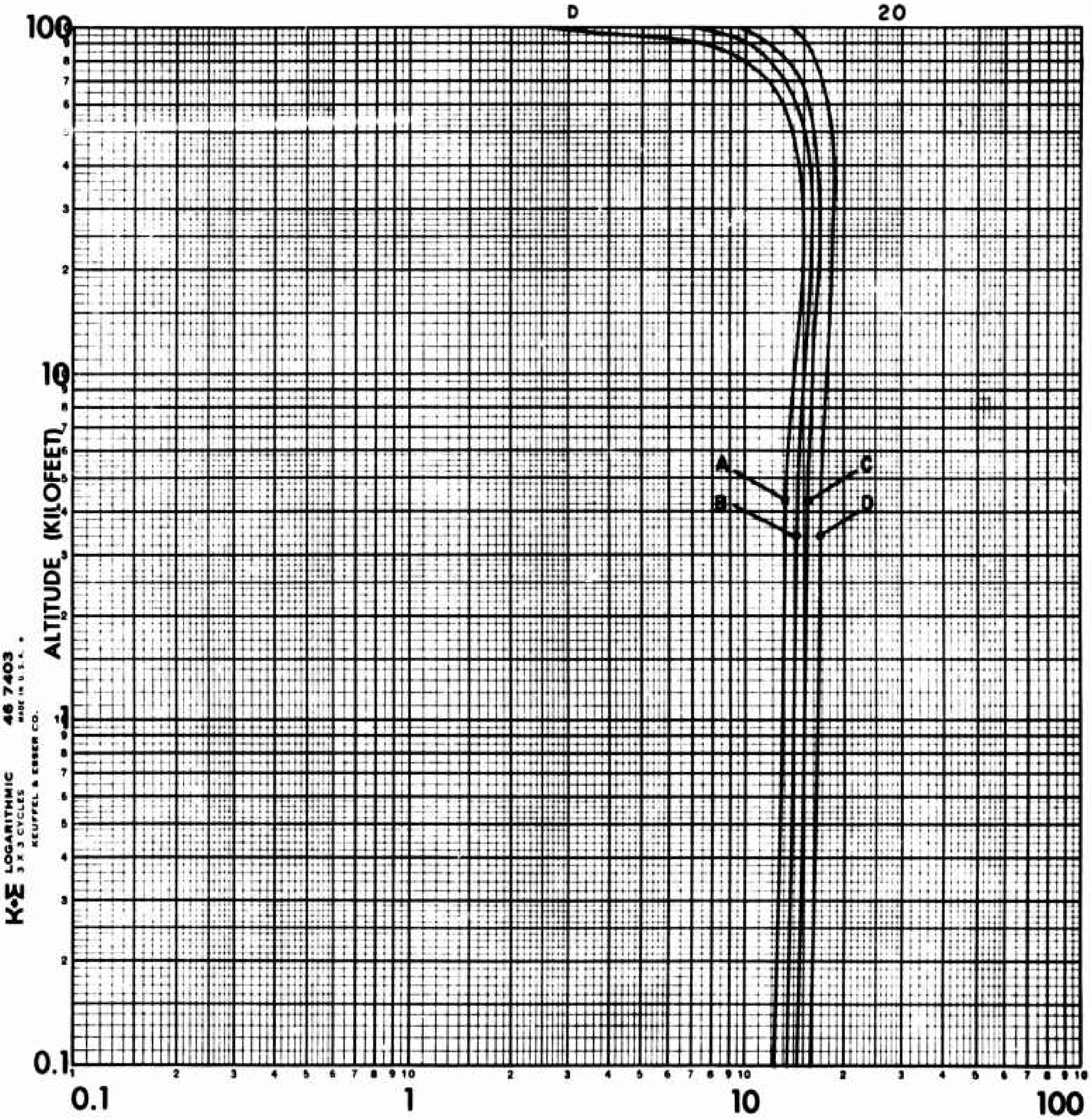
RETINAL BURN

NIGHT MISSION

YIELD: 0.6 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	5
C	10
D	20



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 39

RETINAL BURN

NIGHT MISSION

YIELD: 0.6 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	-
D	-

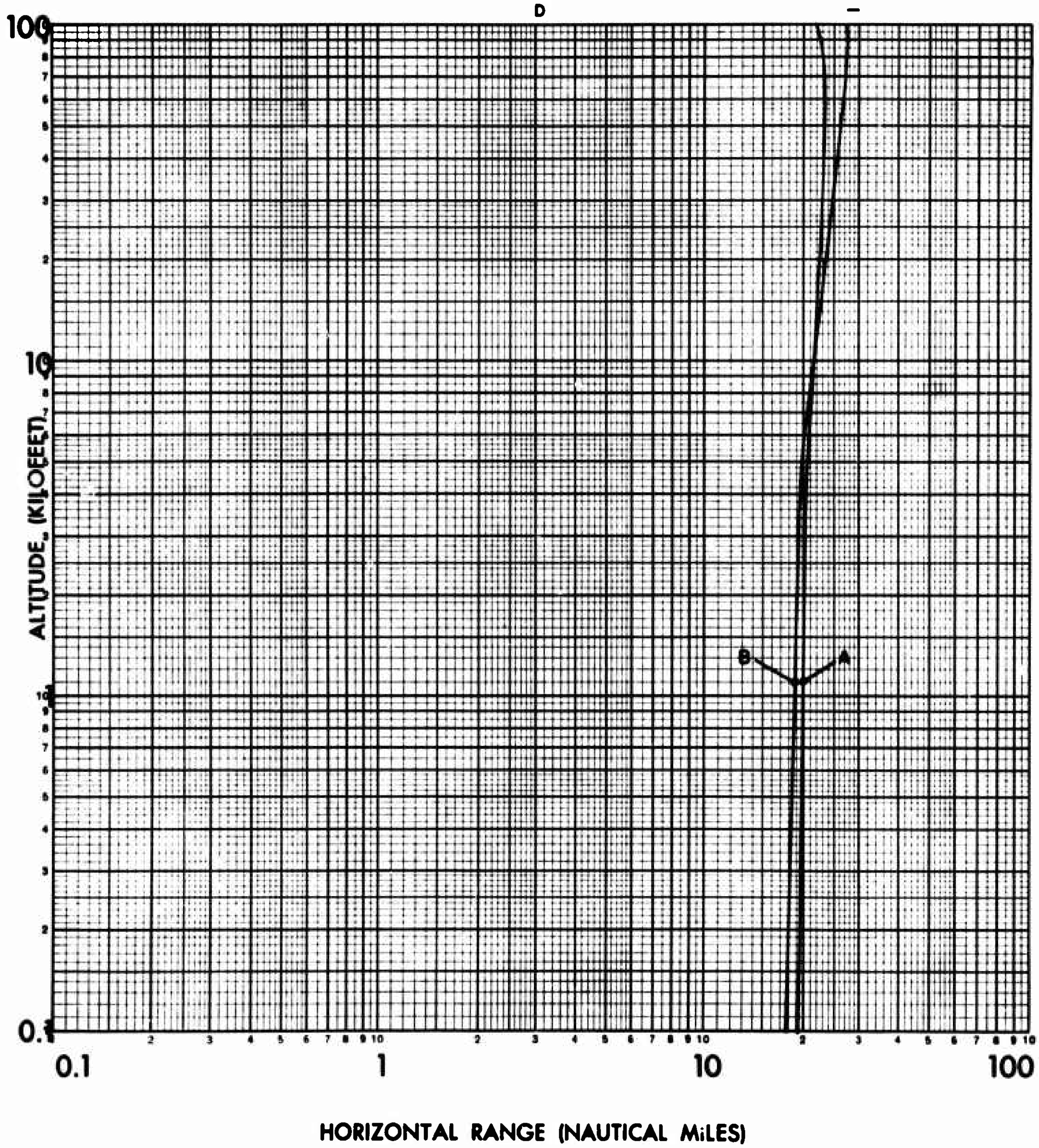


FIGURE 40

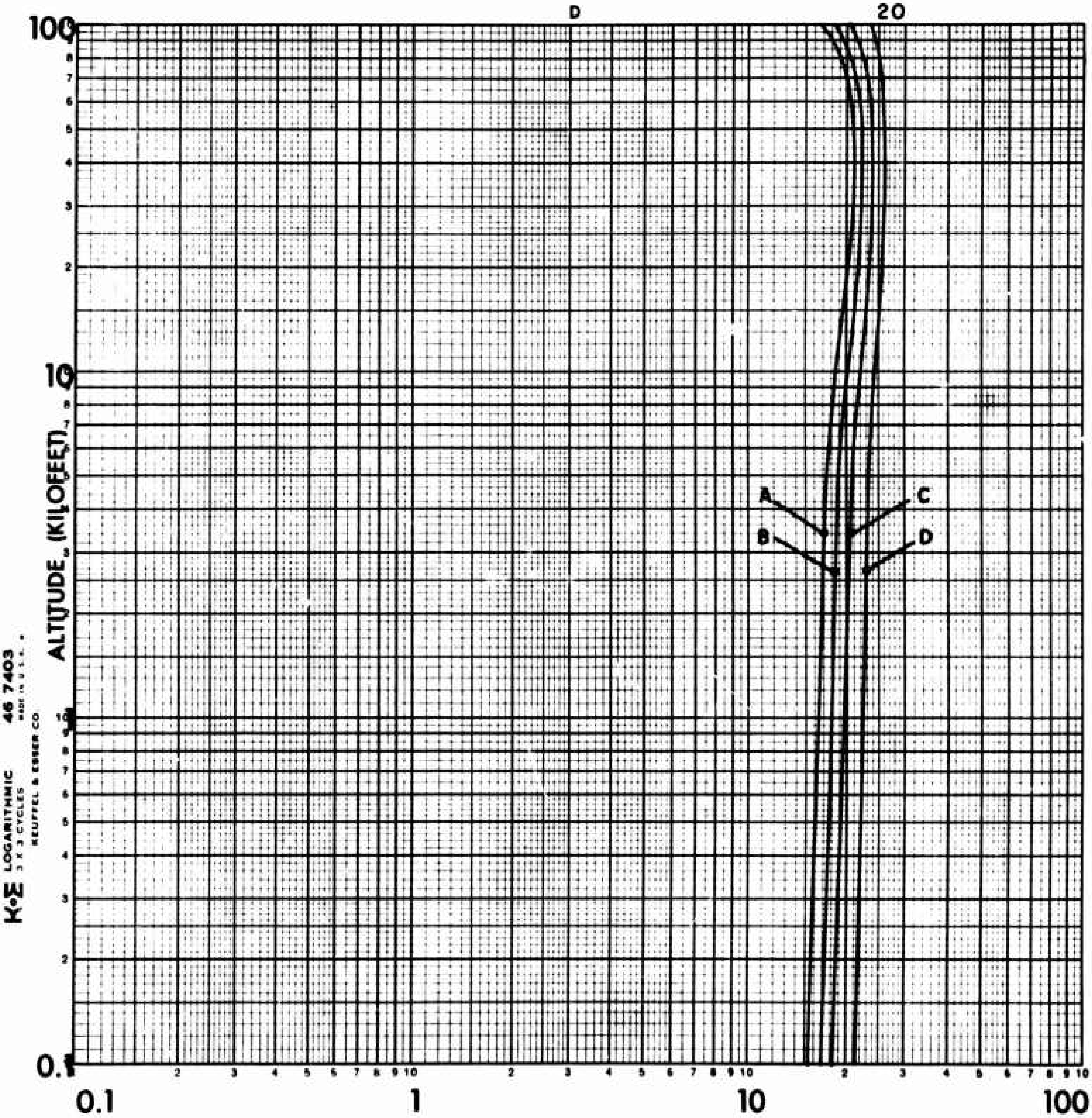
RETINAL BURN

NIGHT MISSION

YIELD: 2.0 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	5
C	10
D	20



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 41

RETINAL BURN

NIGHT MISSION		SYMBOL	BURST ALTITUDE (Kilofeet)
YIELD: 2.0 KT		A	50
FILTER: NONE		B	100
		C	—
		D	—

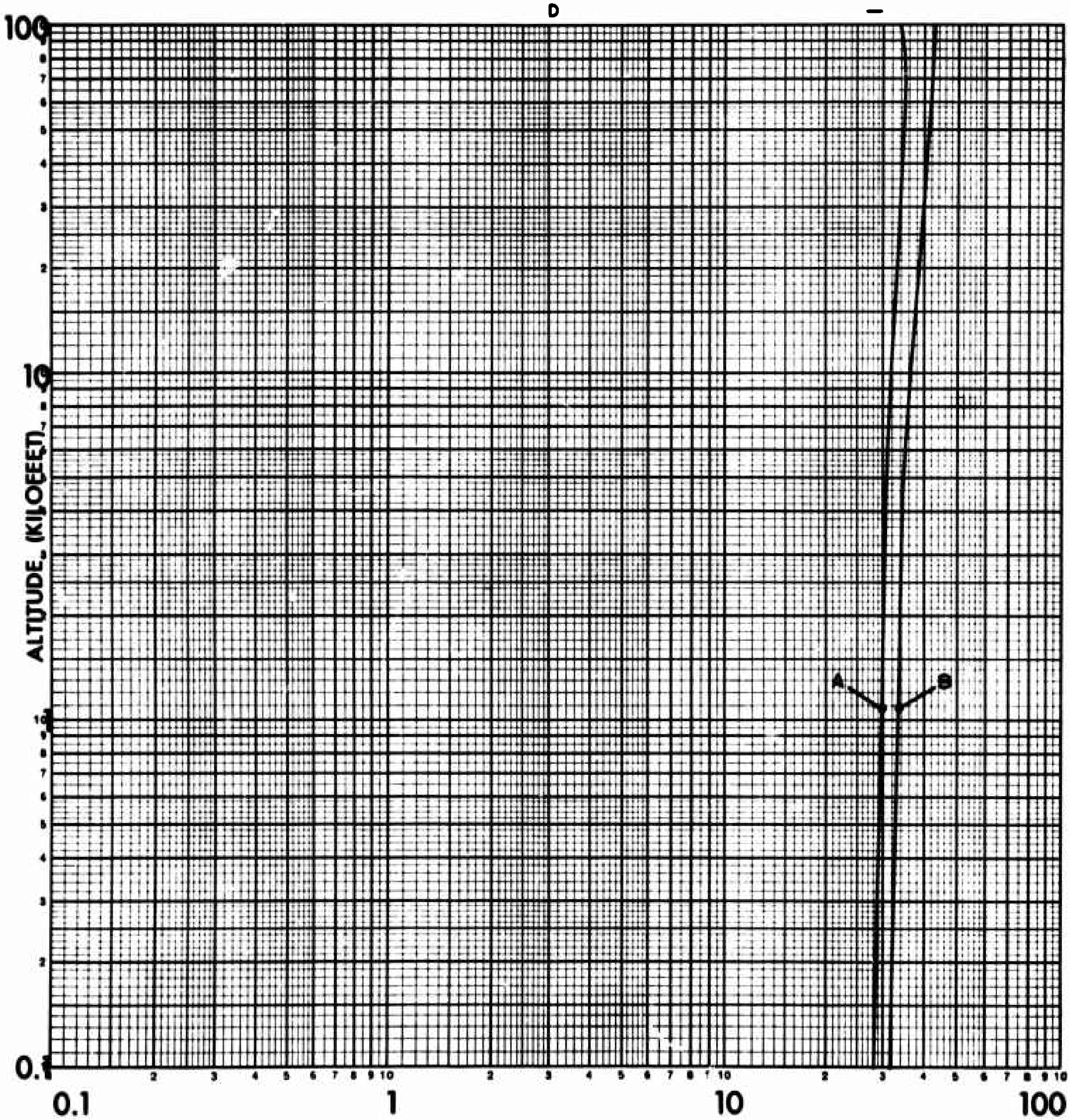


FIGURE 42

RETINAL BURN

NIGHT MISSION

YIELD: 10 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	5
C	10
D	20

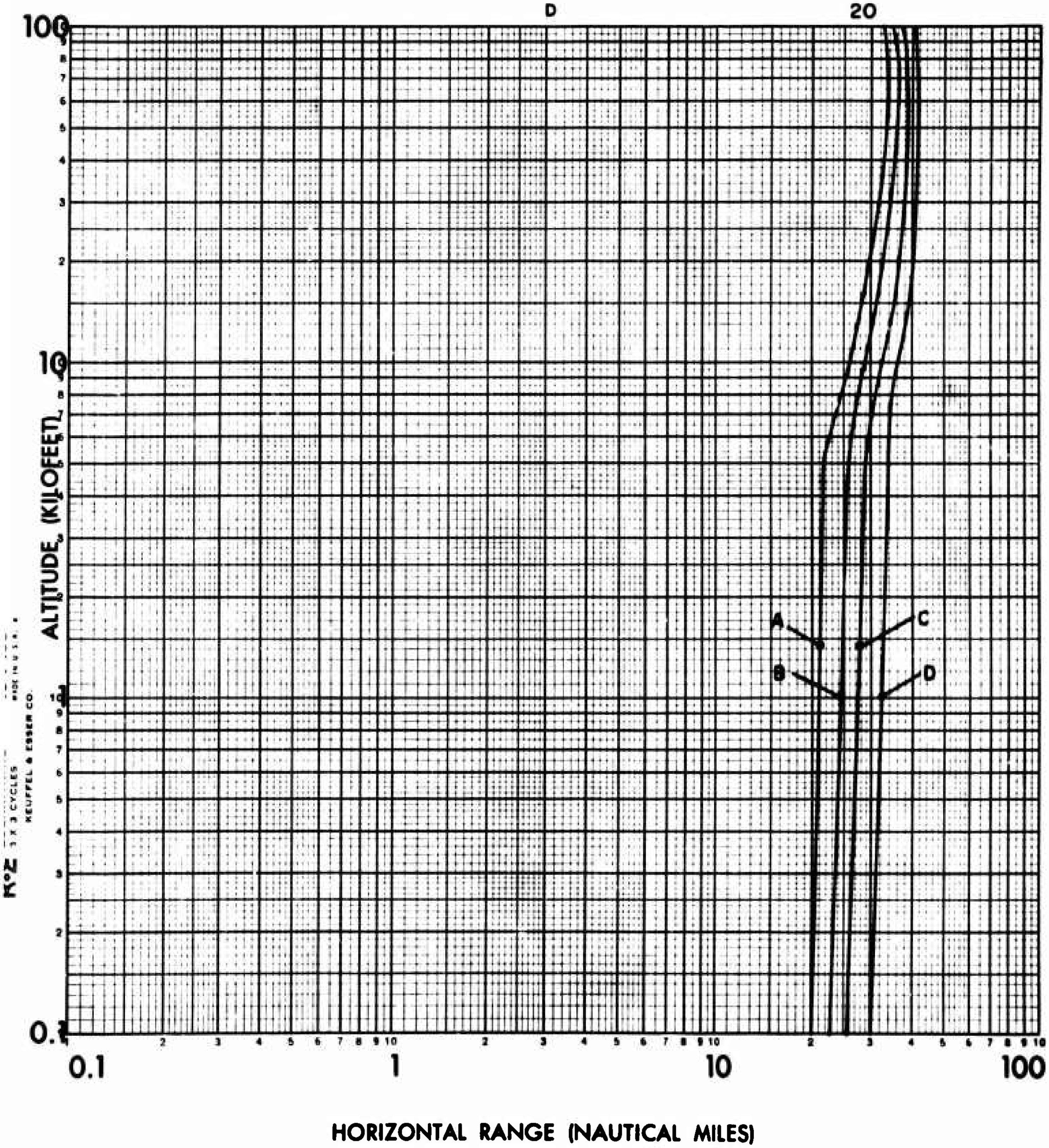


FIGURE 43

RETINAL BURN

NIGHT MISSION

YIELD: 10 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	–
D	–

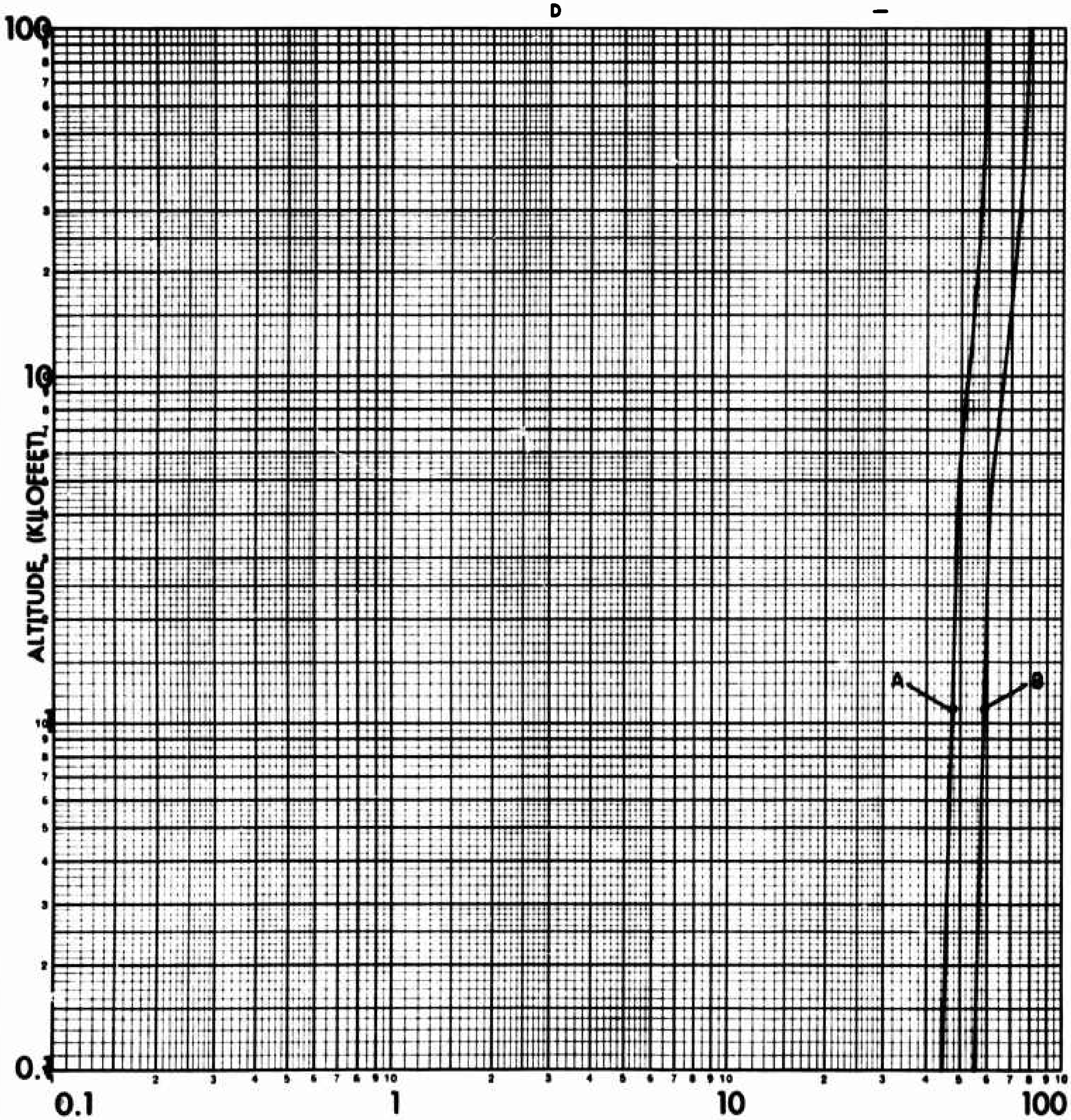


FIGURE 44

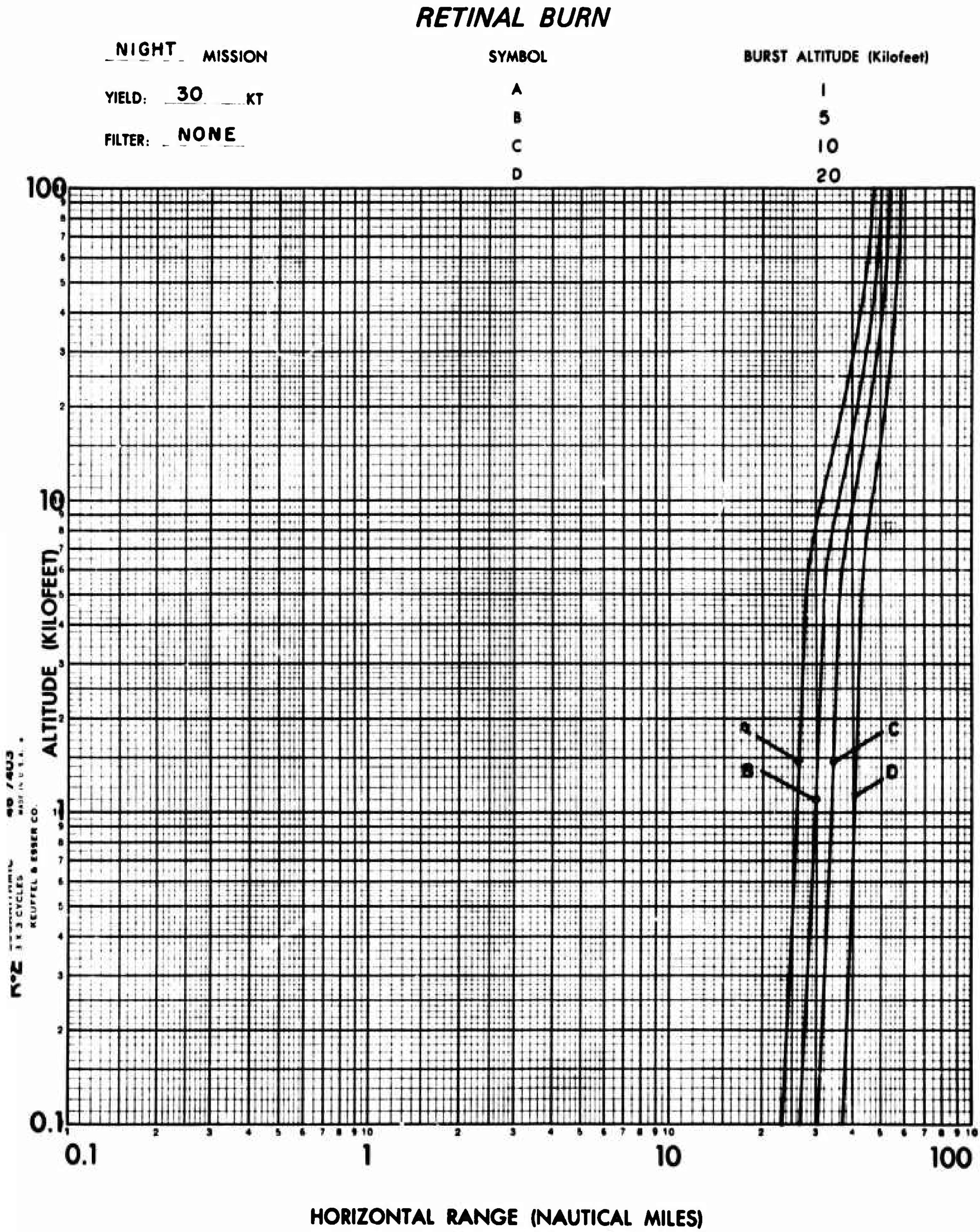
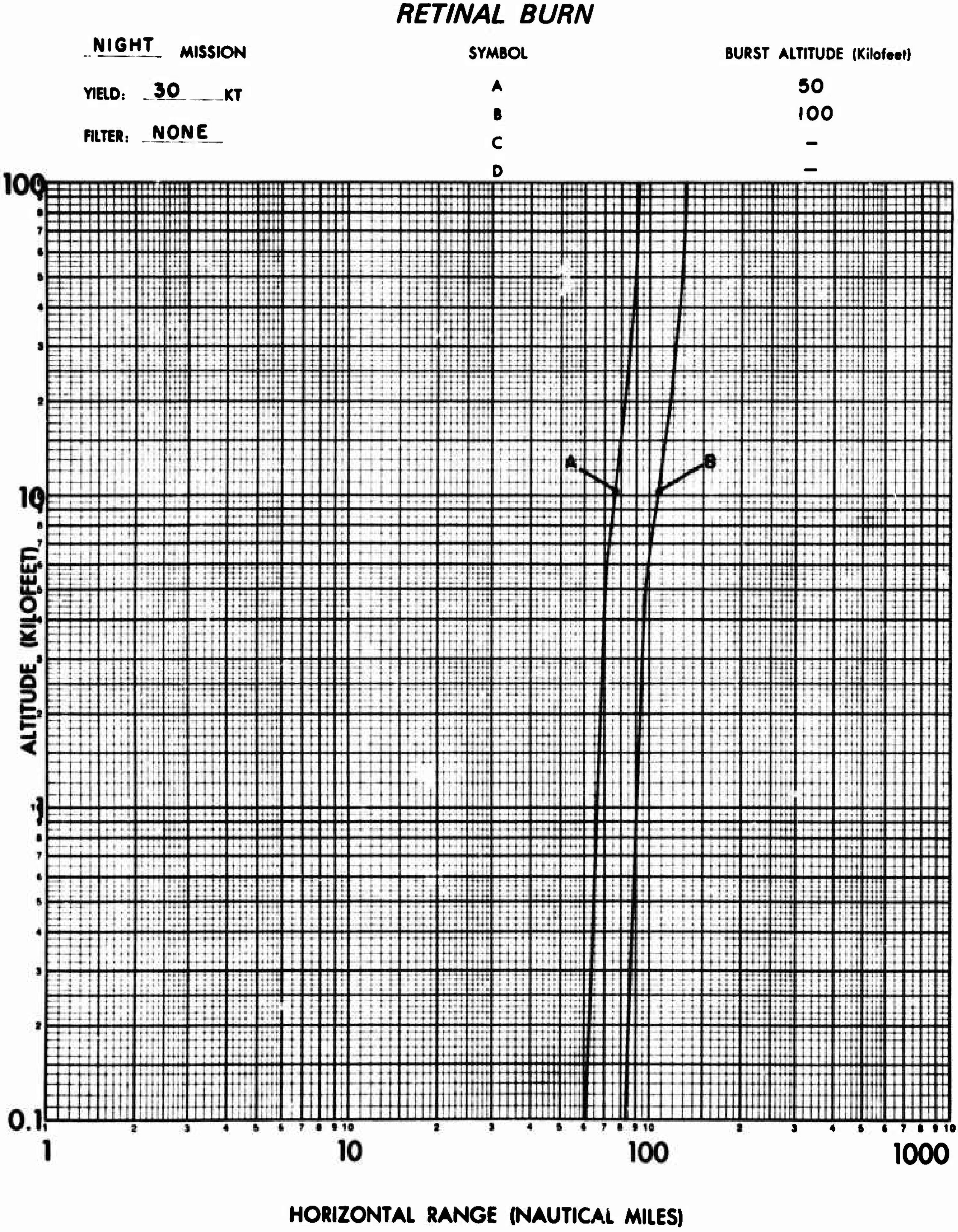

RETINAL BURN
NIGHT MISSION
YIELD: 30 KT
FILTER: NONE
SYMBOL
BURST ALTITUDE (Kilofeet)
A 1
B 5
C 10
D 20
ALTITUDE (KILOFEET)
100
10
1
0.1
0.1
1
10
100
A
B
C
D
HORIZONTAL RANGE (NAUTICAL MILES)
K&E
KEUFFEL & ESSER CO.

FIGURE 45



RETINAL BURN
NIGHT MISSION
YIELD: 30 KT
FILTER: NONE
SYMBOL
BURST ALTITUDE (Kilofeet)
A 50
B 100
C –
D –
100
10
1
0.1
ALTITUDE (KILOFEET)
1
10
100
1000
HORIZONTAL RANGE (NAUTICAL MILES)
A
B

FIGURE 46

RETINAL BURN

NIGHT MISSION	SYMBOL	BURST ALTITUDE (Kilofeet)
YIELD: 60 KT	A	1
FILTER: NONE	B	5
	C	10
	D	20

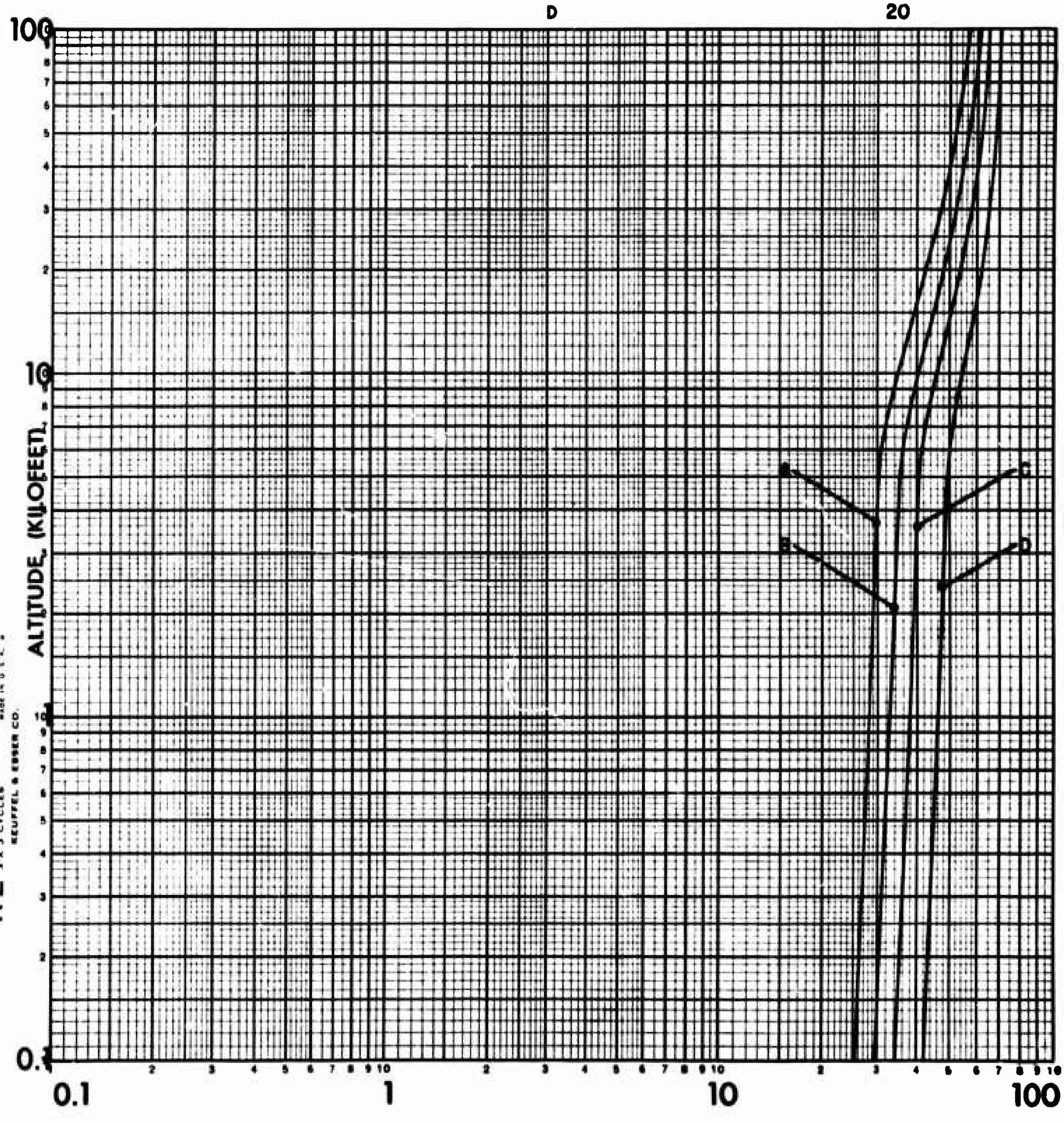


FIGURE 47

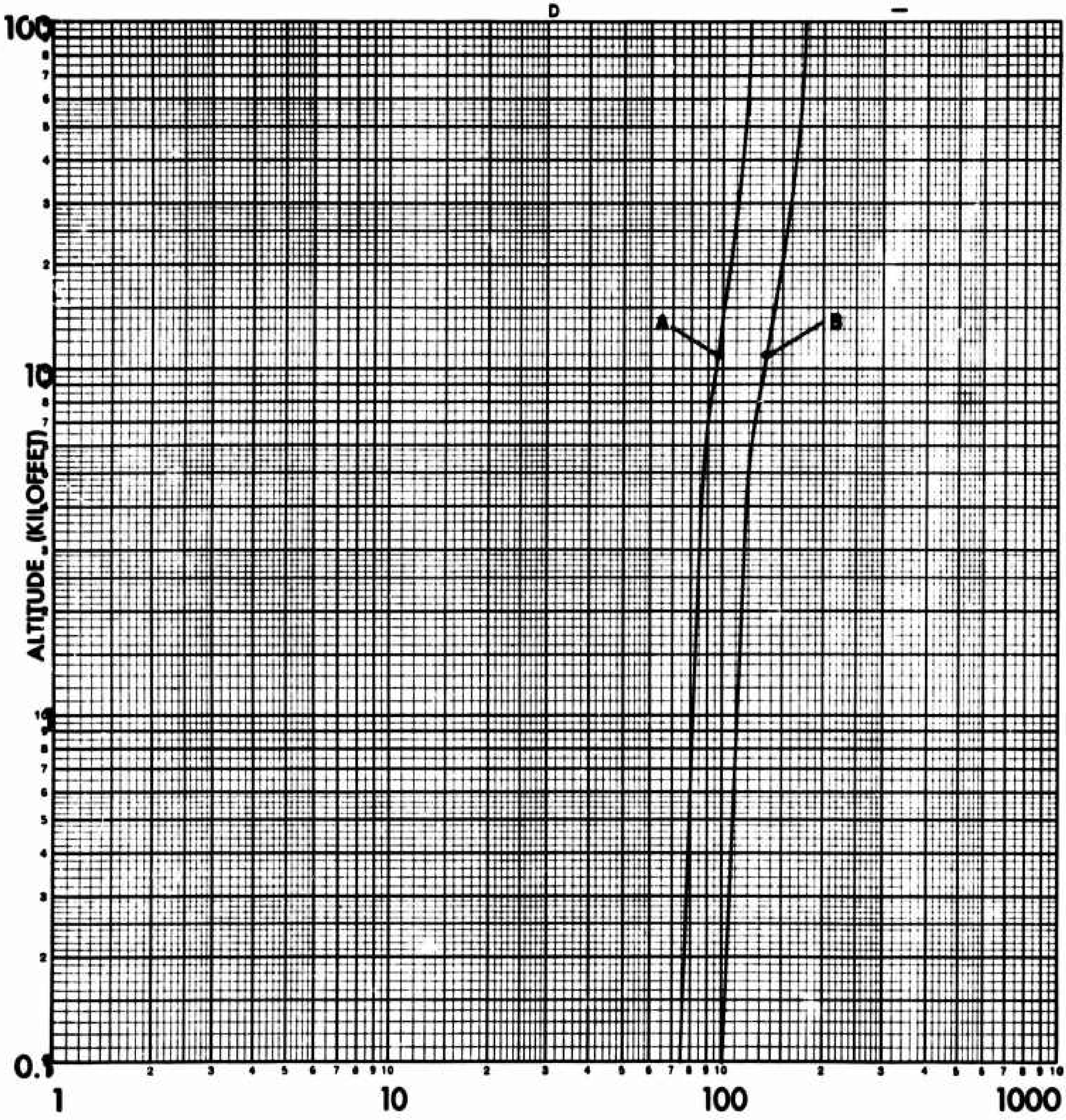
RETINAL BURN

NIGHT MISSION

YIELD: 60 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	—
D	—



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 48

RETINAL BURN

NIGHT MISSION

YIELD: 200 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1.5
B	5.0
C	10.0
D	20.0

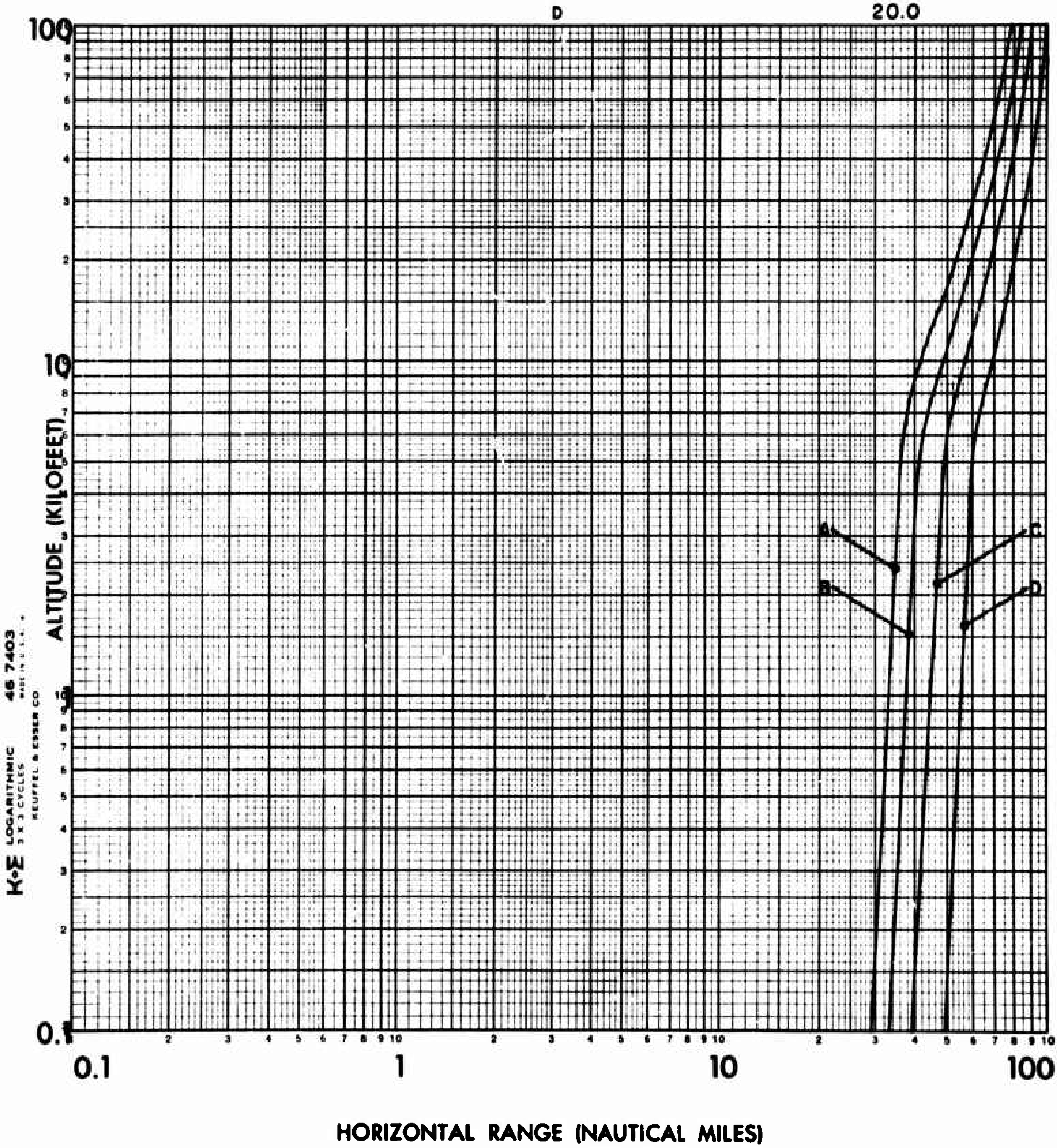


FIGURE 49

RETINAL BURN

NIGHT MISSION

YIELD: 200 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	–
D	–

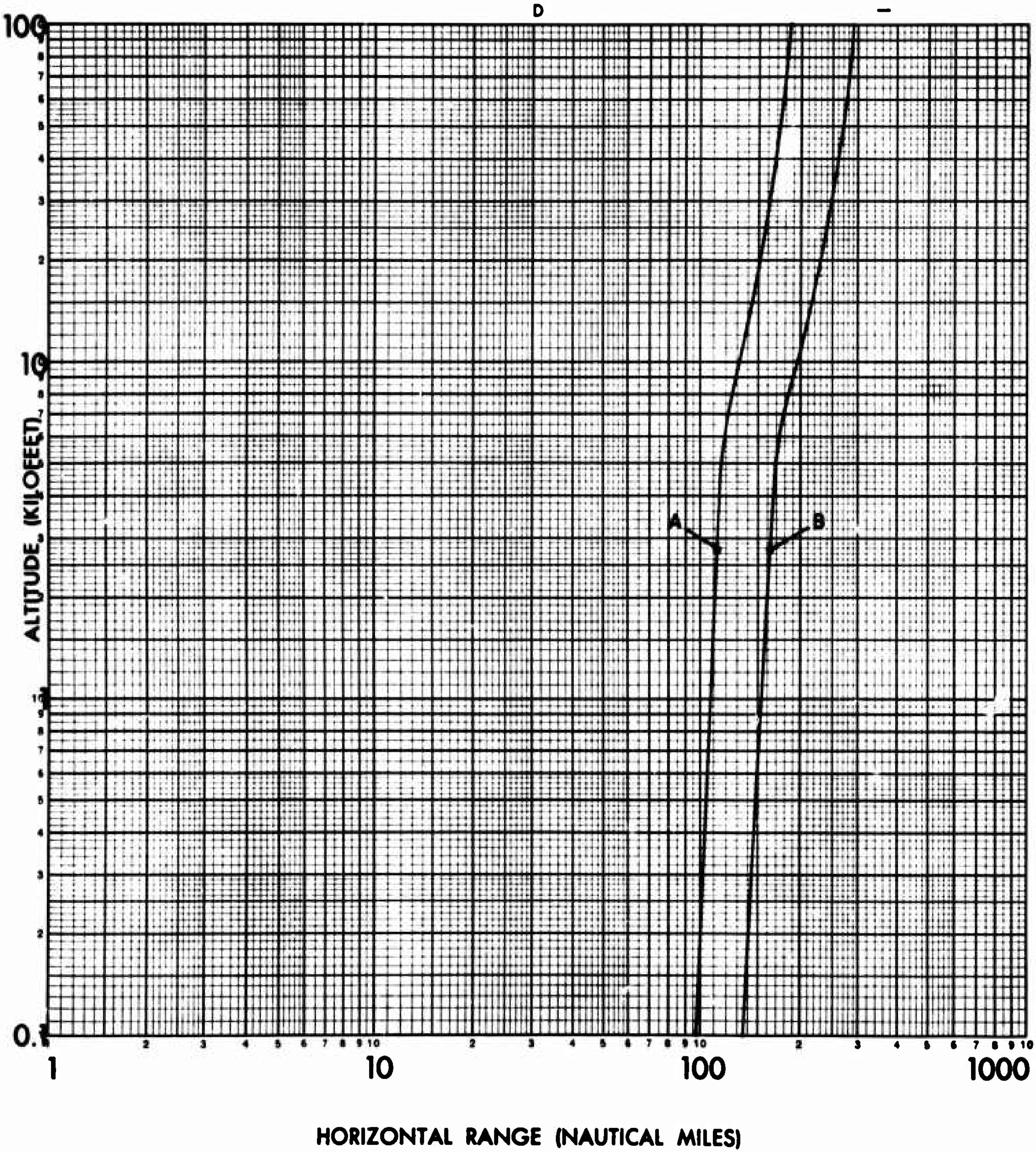


FIGURE 50

RETINAL BURN

NIGHT MISSION

YIELD: 440 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1.5
B	5
C	10
D	20

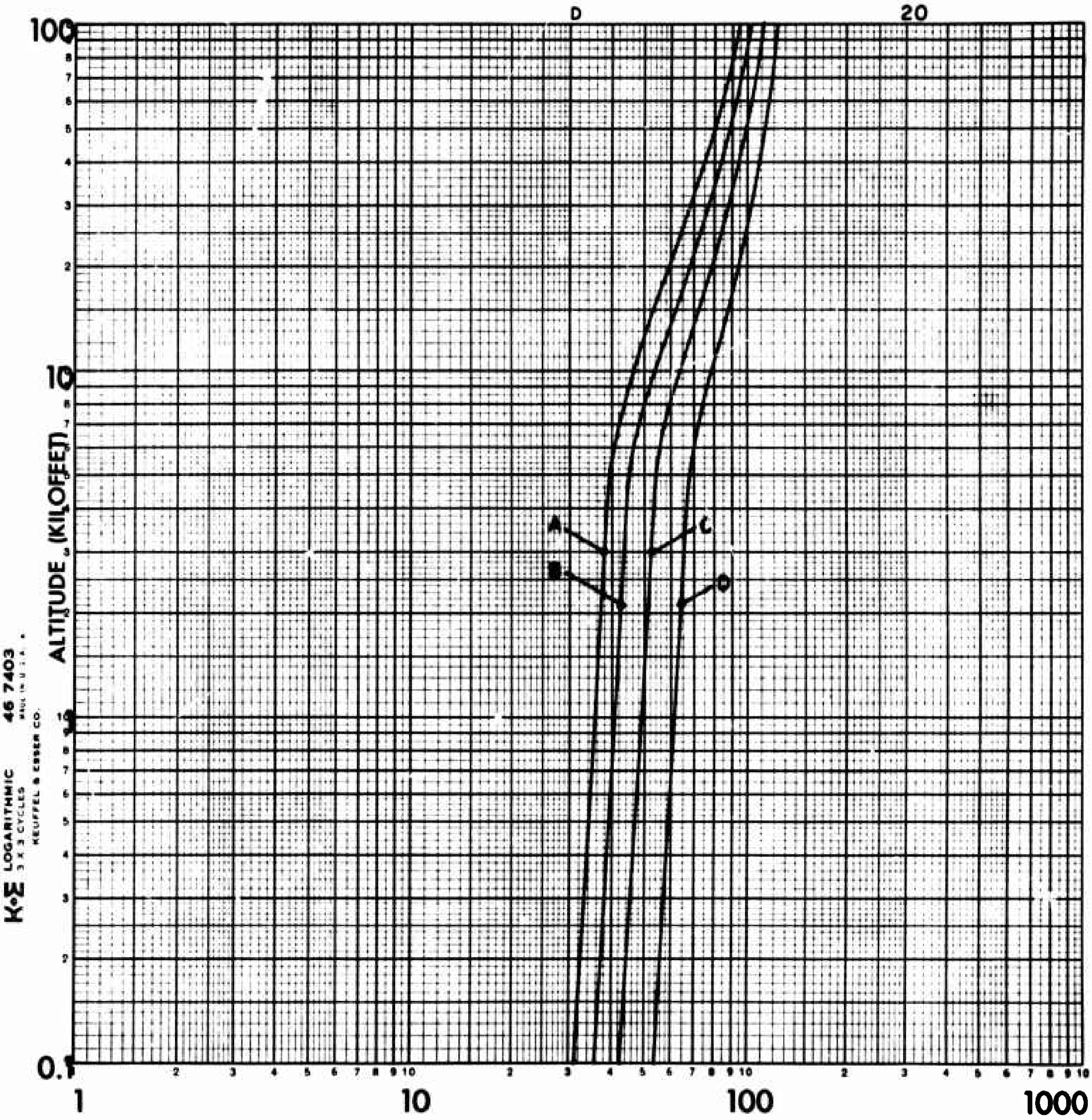


FIGURE 51

RETINAL BURN

NIGHT MISSION

YIELD: 440 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	–
D	–

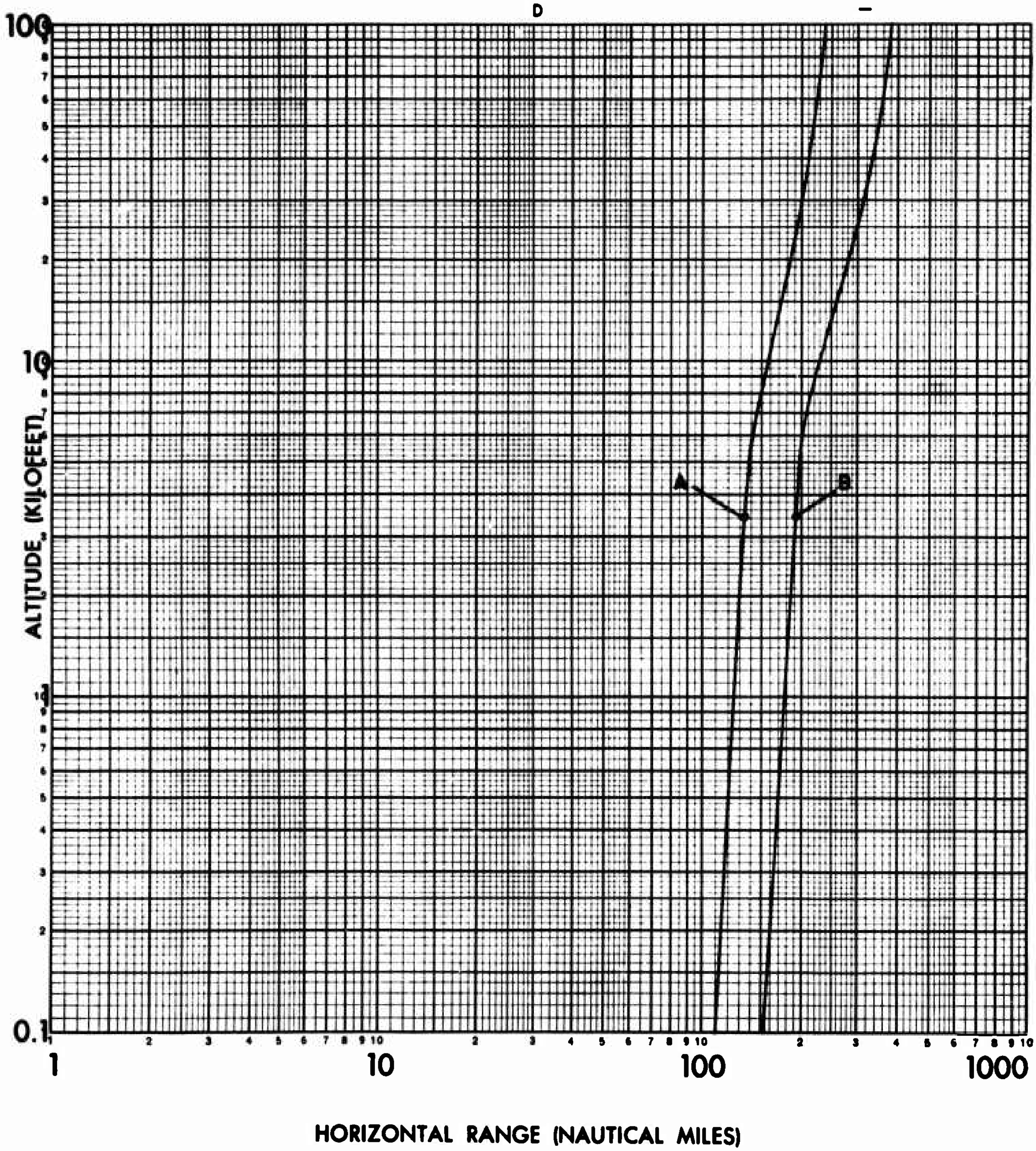


FIGURE 52

RETINAL BURN

NIGHT MISSION

YIELD: 1000 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	3
B	10
C	25
D	50

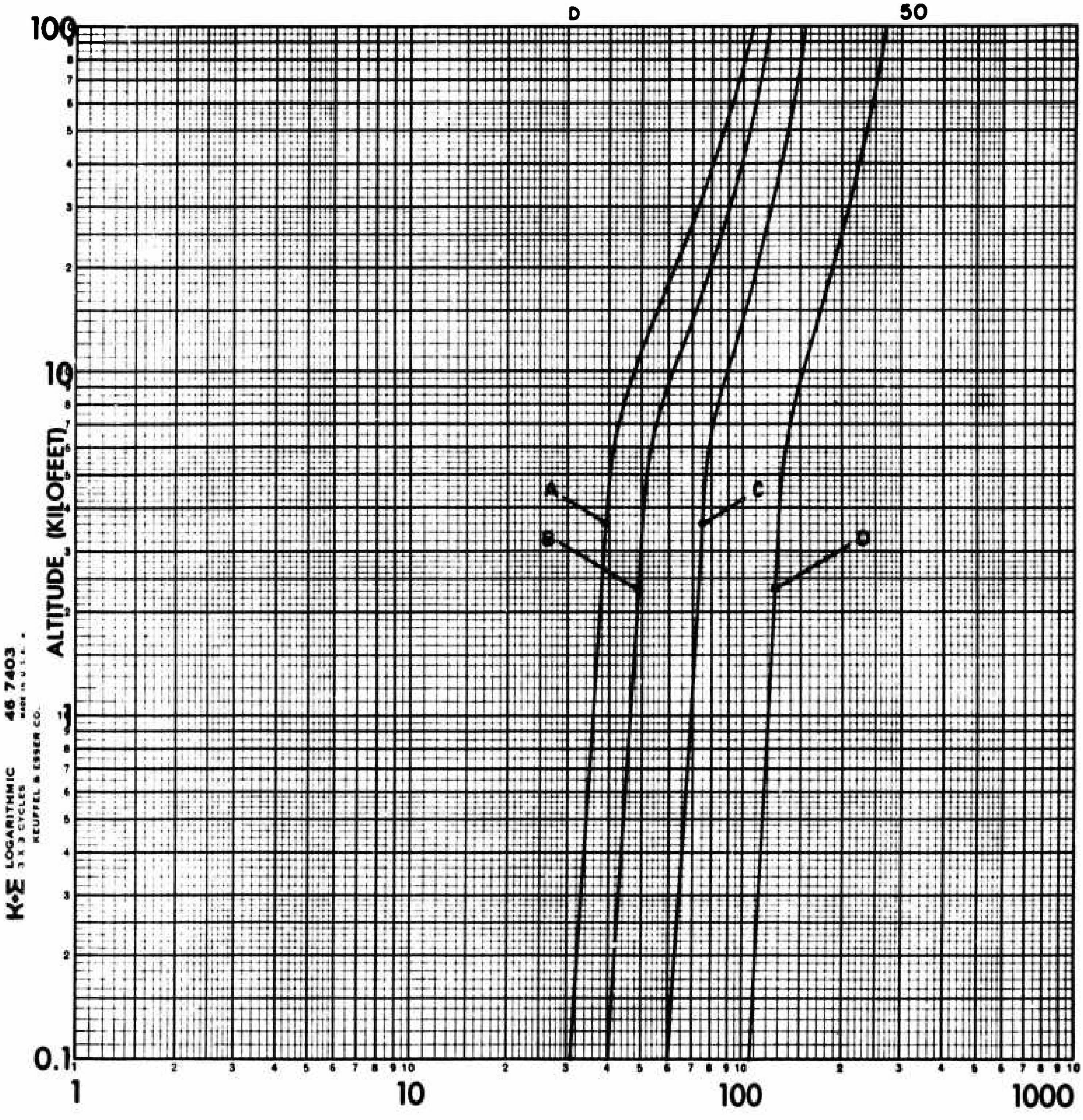


FIGURE 53

RETINAL BURN

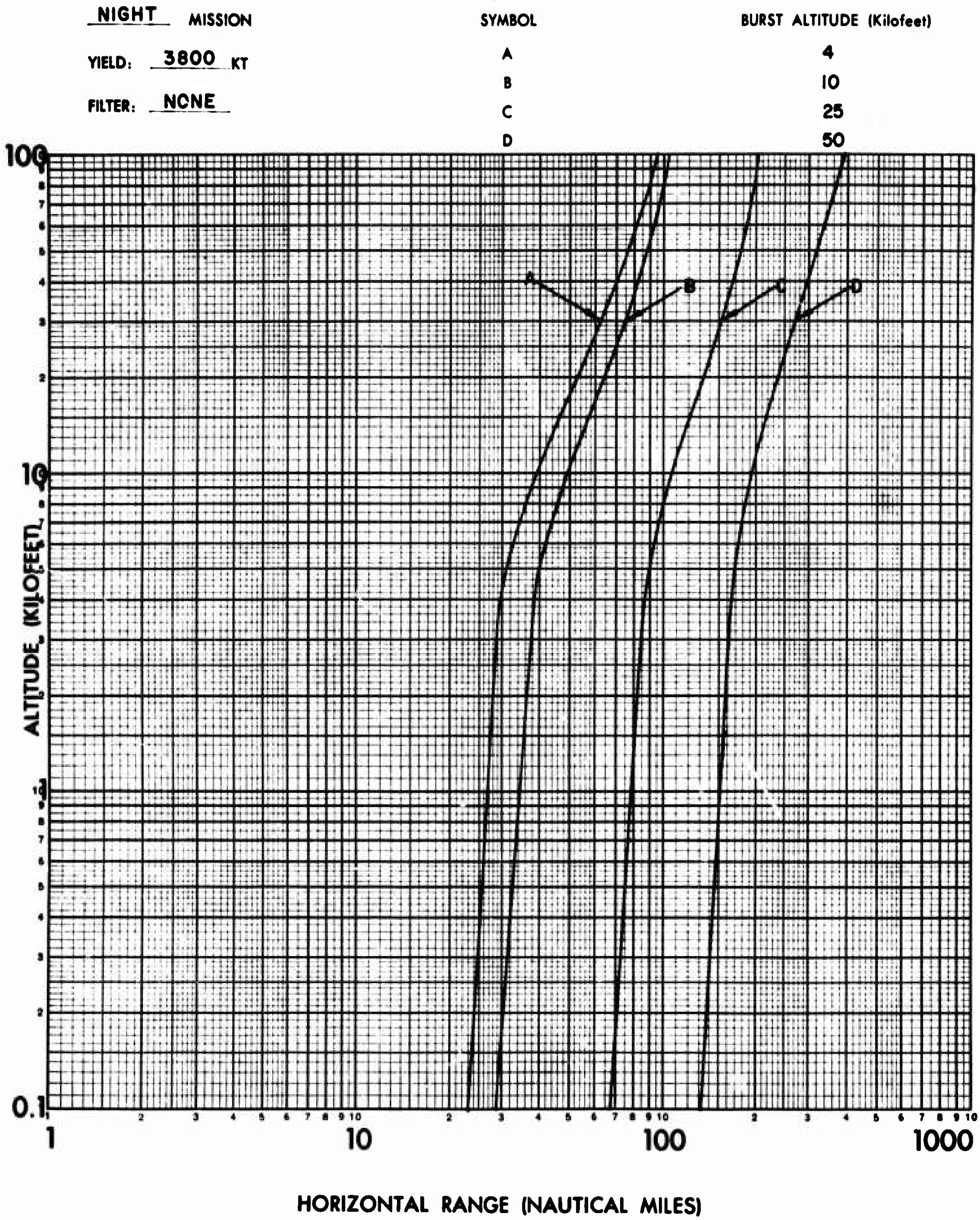


FIGURE 54

RETINAL BURN

NIGHT MISSION

YIELD: 9000 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	5
B	10
C	25
D	50

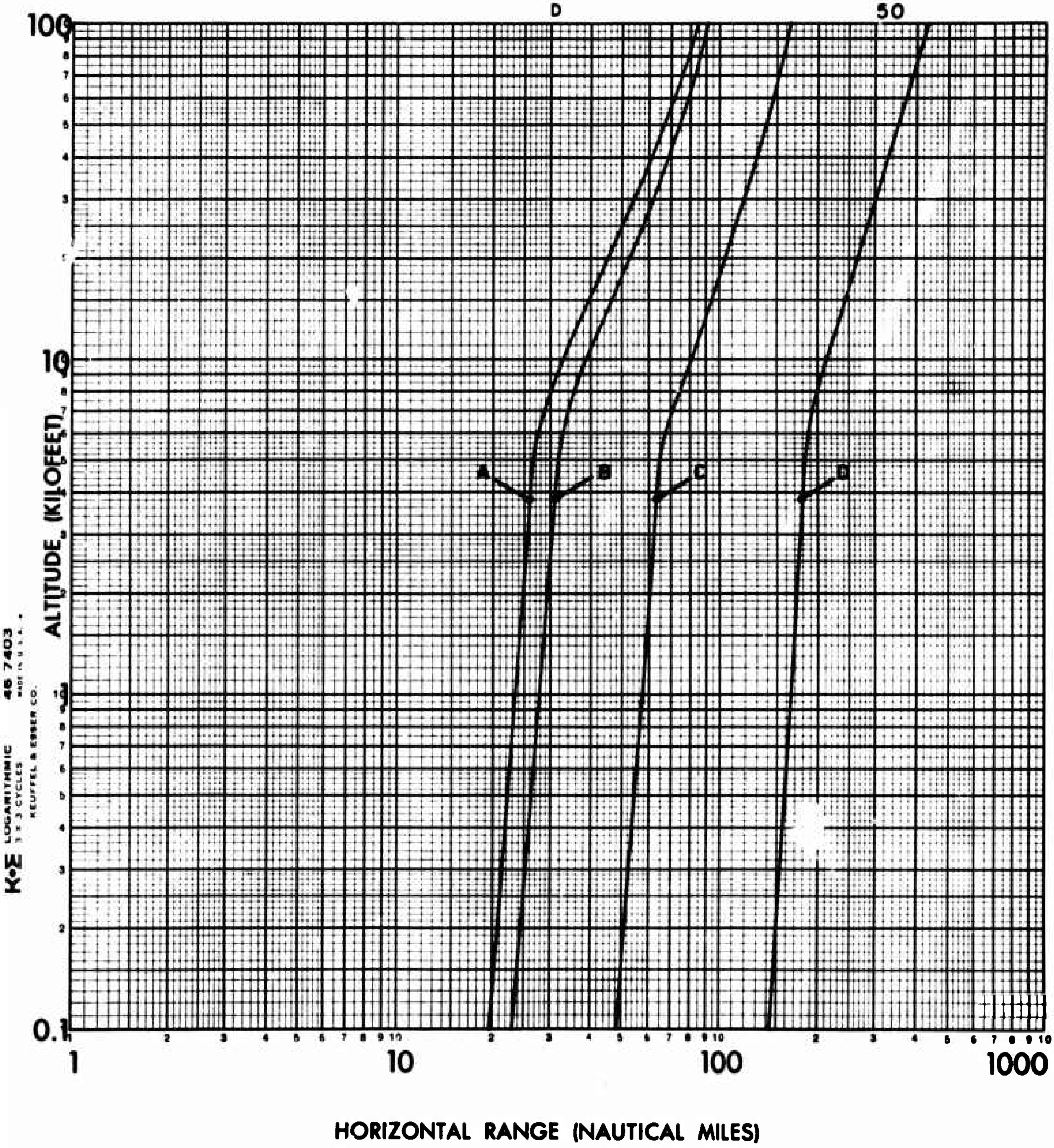


FIGURE 55

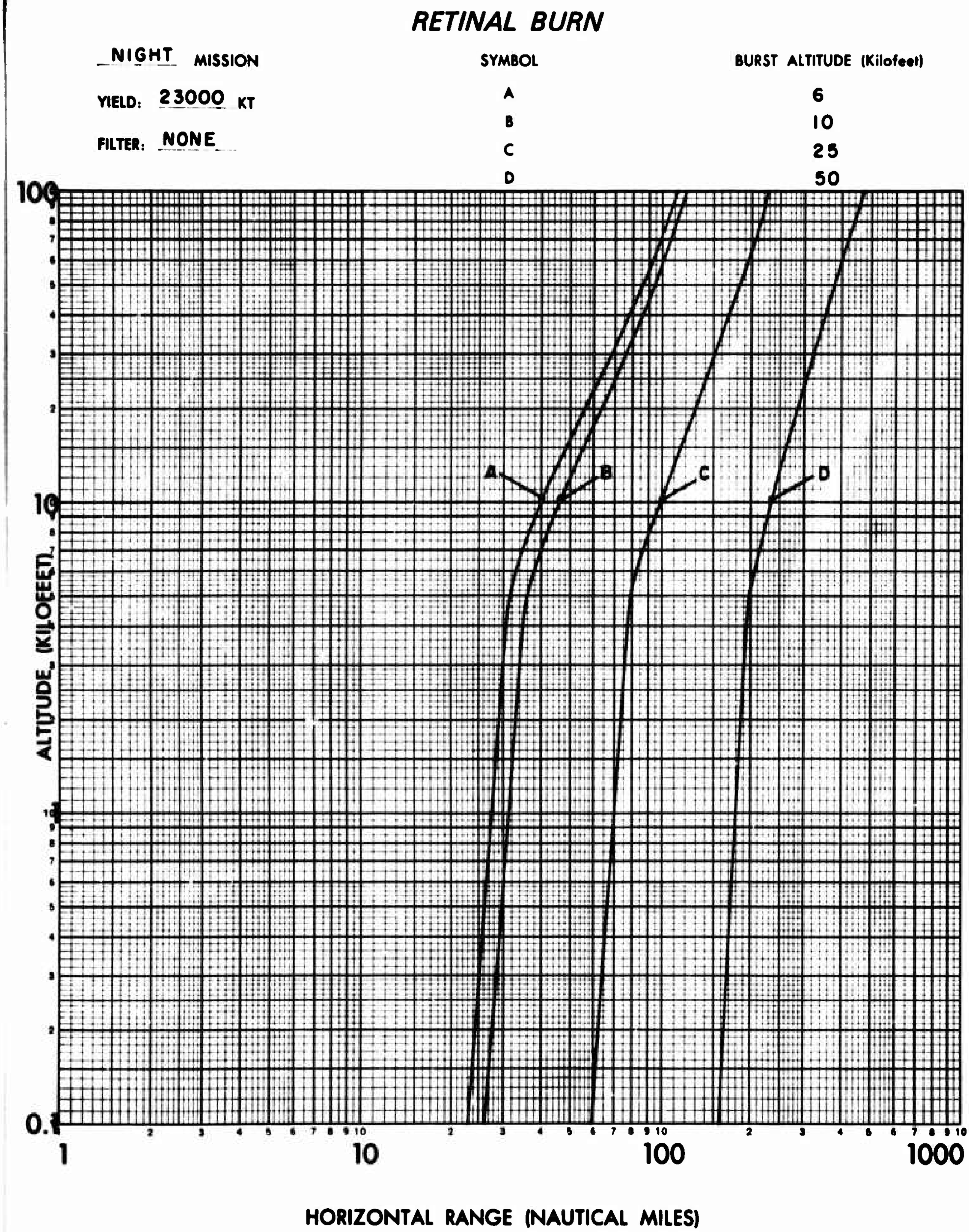

RETINAL BURN
NIGHT MISSION
YIELD: 23000 KT
FILTER: NONE
SYMBOL
BURST ALTITUDE (Kilofeet)
A 6
B 10
C 25
D 50
A
B
C
D
100
10
0.1
ALTITUDE (KILOFEET)
1
10
100
1000
HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 56

FLASHBLINDNESS SAFE SEPARATION ENVELOPES

DAY MISSION

FLASHBLINDNESS

DAY MISSION

YIELD: 0.02 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	10
C	25
D	50

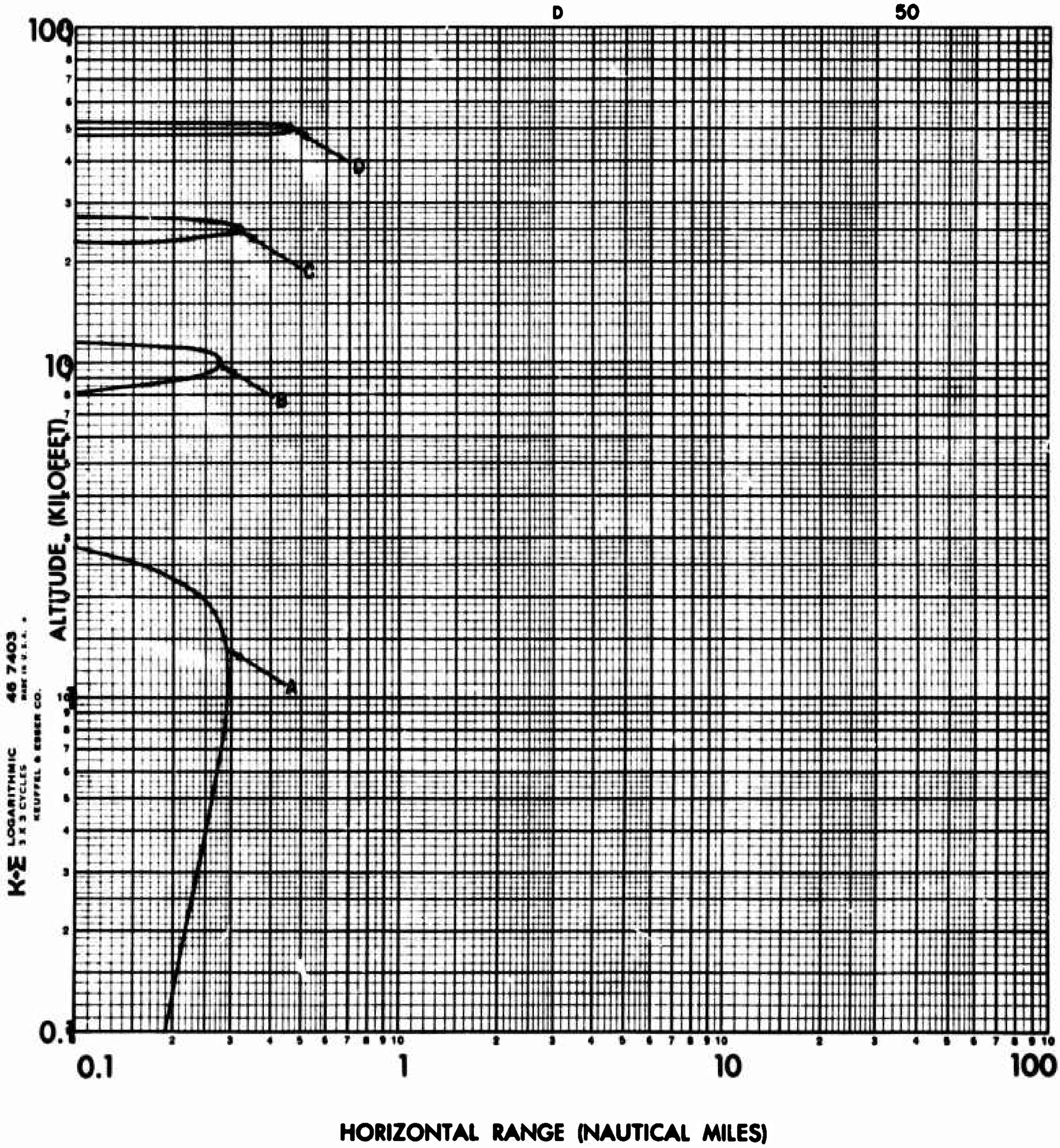


FIGURE 57

FLASHBLINDNESS

DAY MISSION

YIELD: 0.02 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	75
B	100
C	
D	

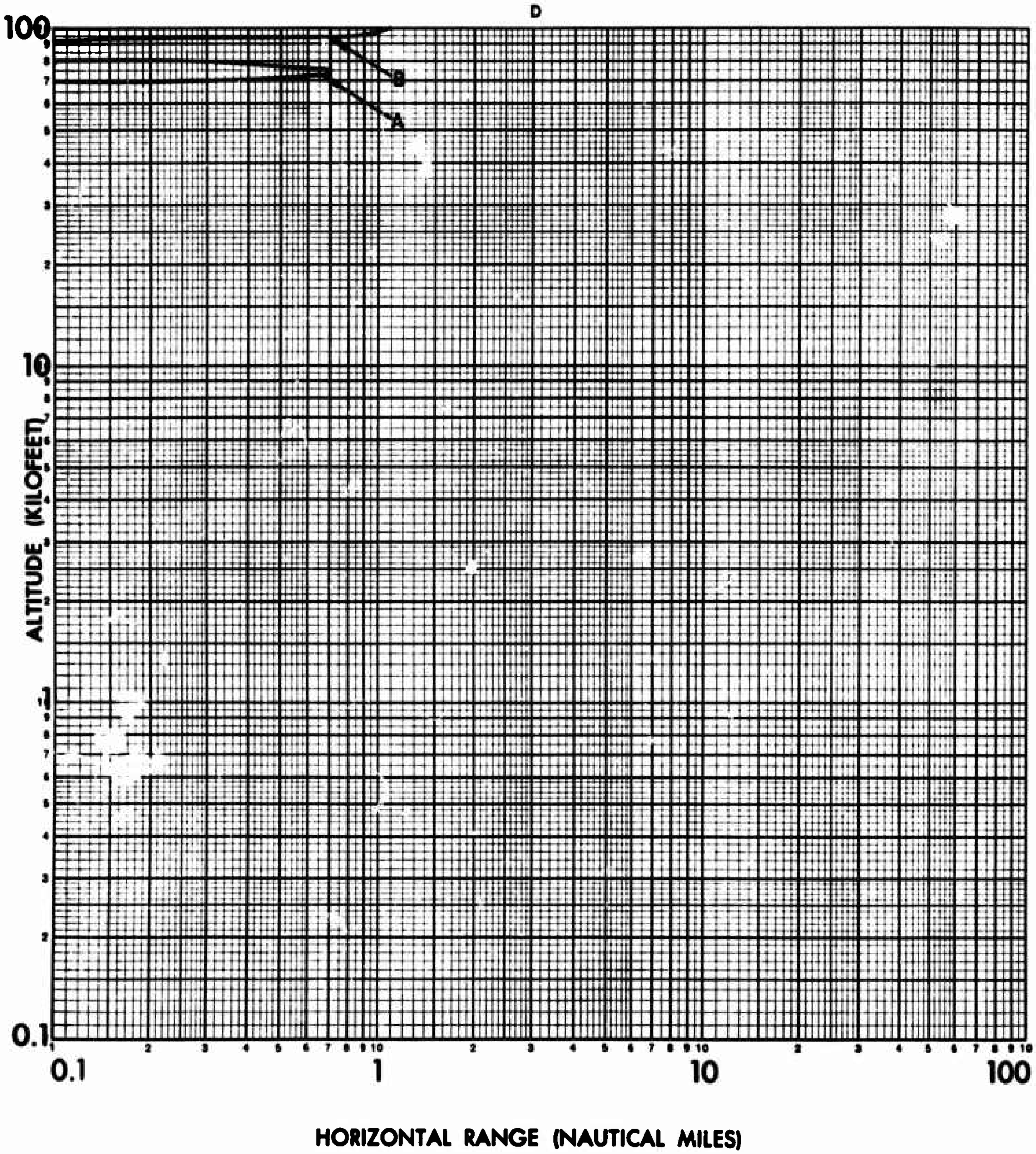


FIGURE 58

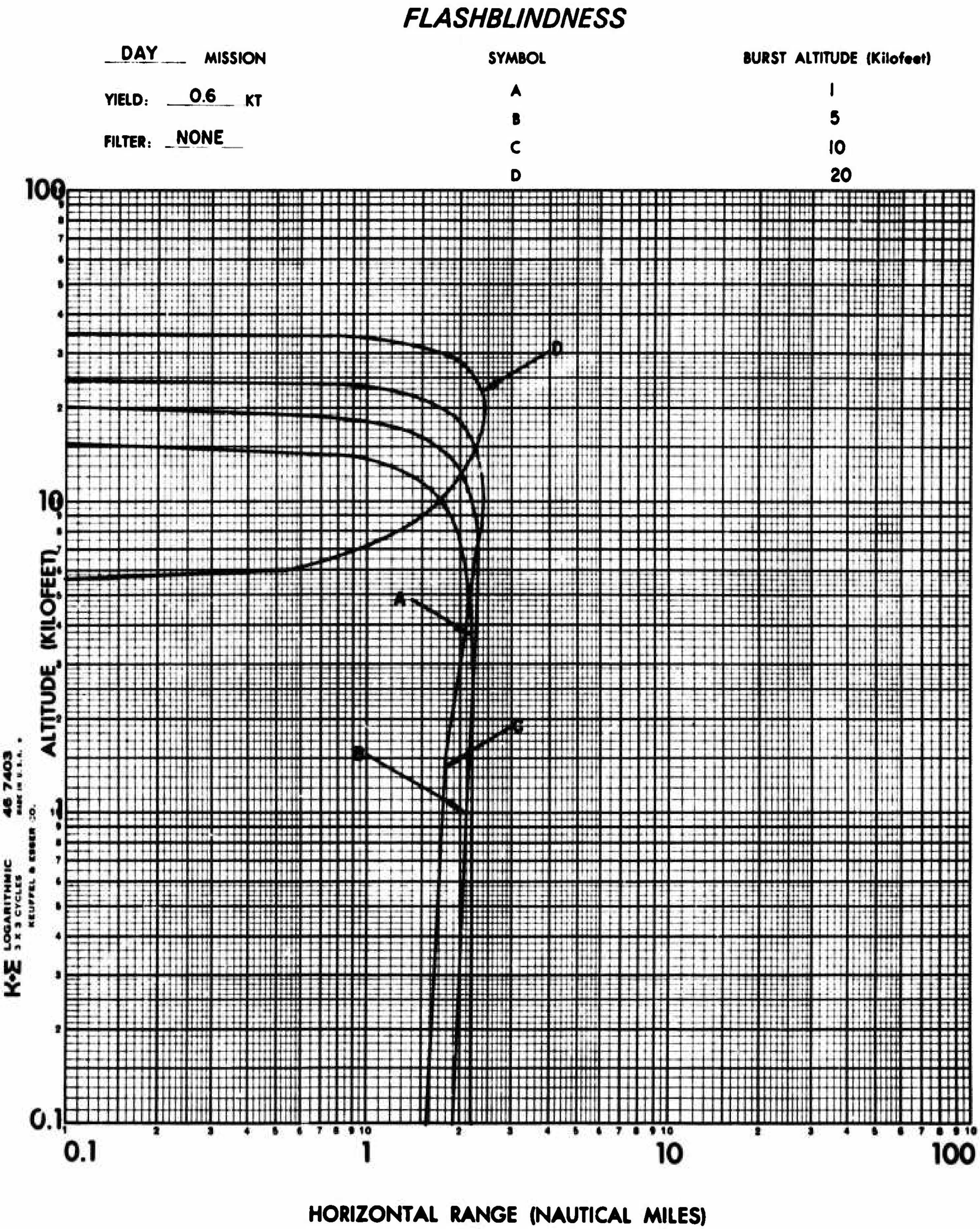

FLASHBLINDNESS
DAY MISSION
YIELD: 0.6 KT
FILTER: NONE
SYMBOL
A
B
C
D
BURST ALTITUDE (Kilofeet)
1
5
10
20
100
10
0.1
ALTITUDE (KILOFEET)
0.1
1
10
100
HORIZONTAL RANGE (NAUTICAL MILES)
K+E LOGARITHMIC 46 7403
3 X 3 CYCLES
KEUFFEL & ESSER CO.

FIGURE 59

FLASHBLINDNESS

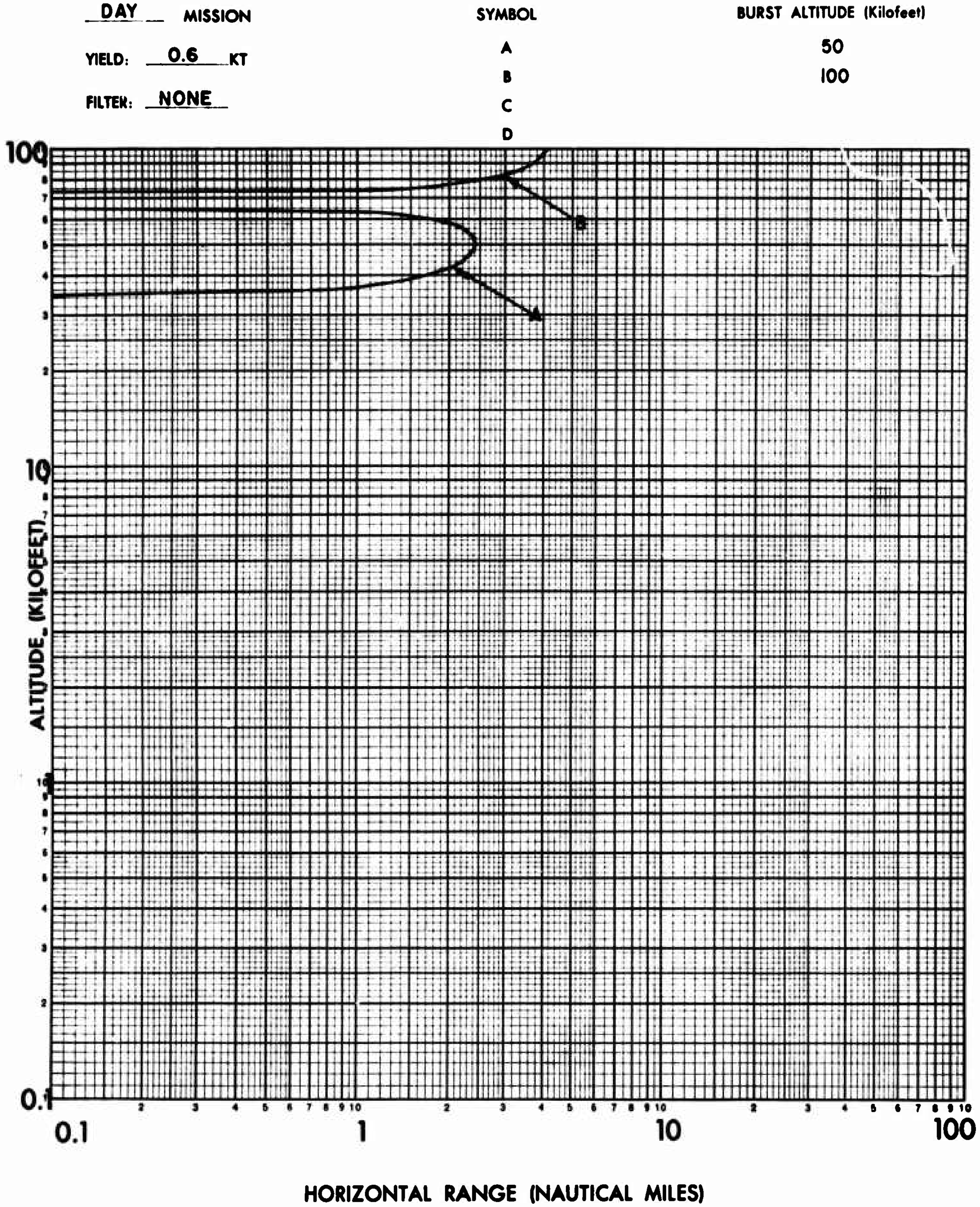


FIGURE 60

FLASHBLINDNESS

DAY MISSION

YIELD: 2 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	5
C	10
D	20

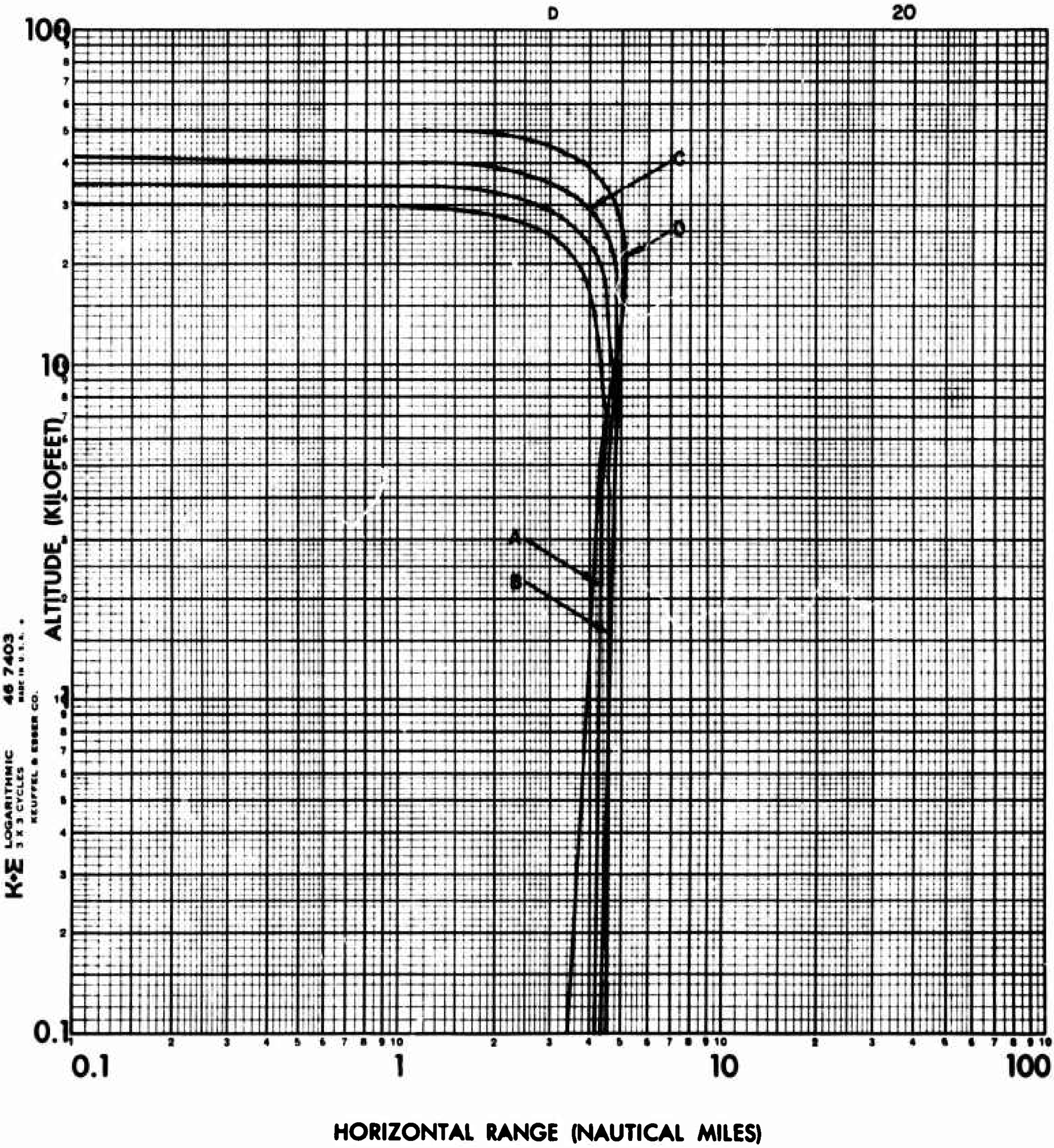


FIGURE 61

FLASHBLINDNESS

DAY MISSION

YIELD: 2 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	

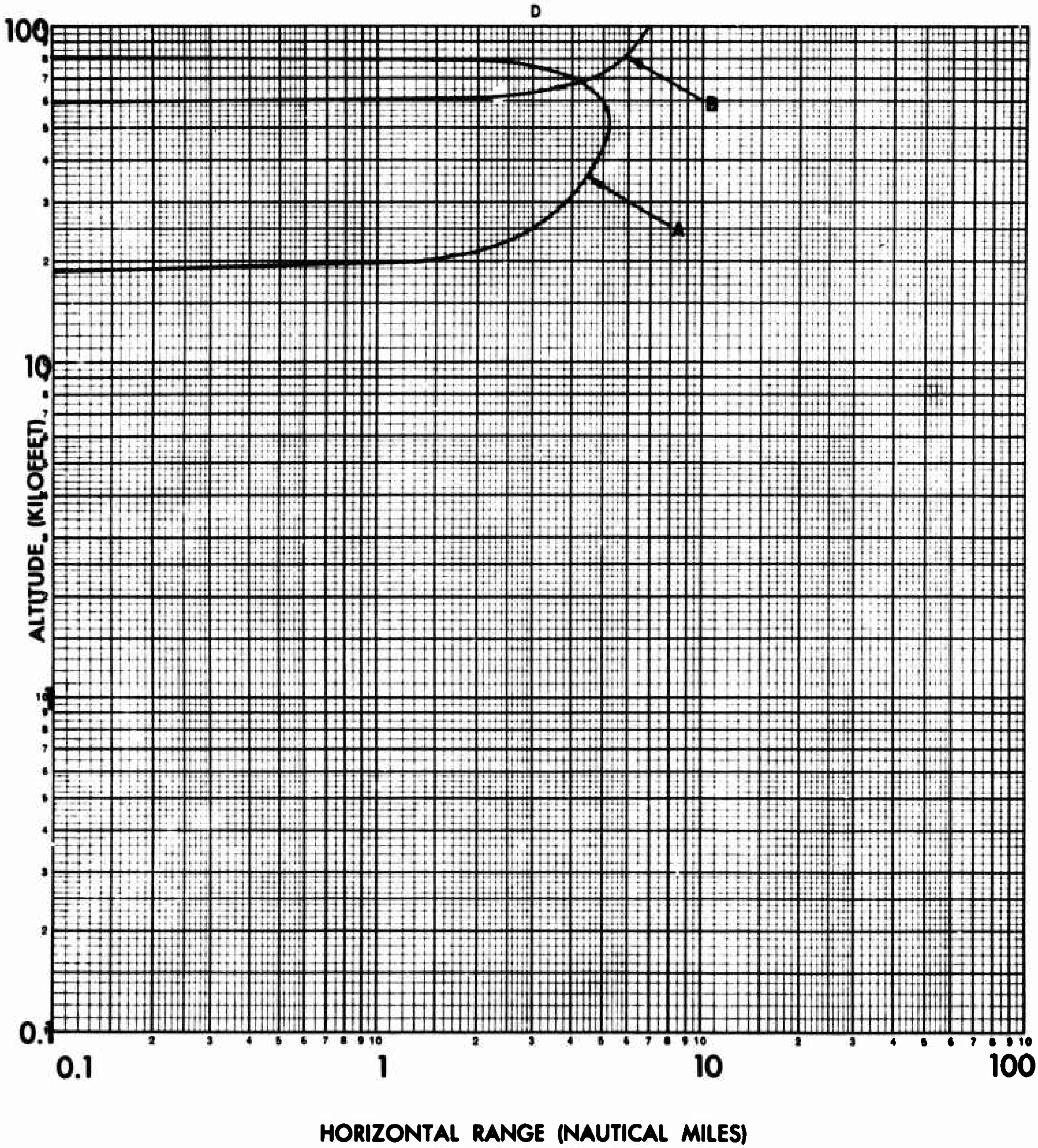


FIGURE 62

FLASHBLINDNESS

DAY MISSION	SYMBOL	BURST ALTITUDE (Kilofeet)
YIELD: 10 KT	A	1
FILTER: NONE	B	5
	C	10
	D	20

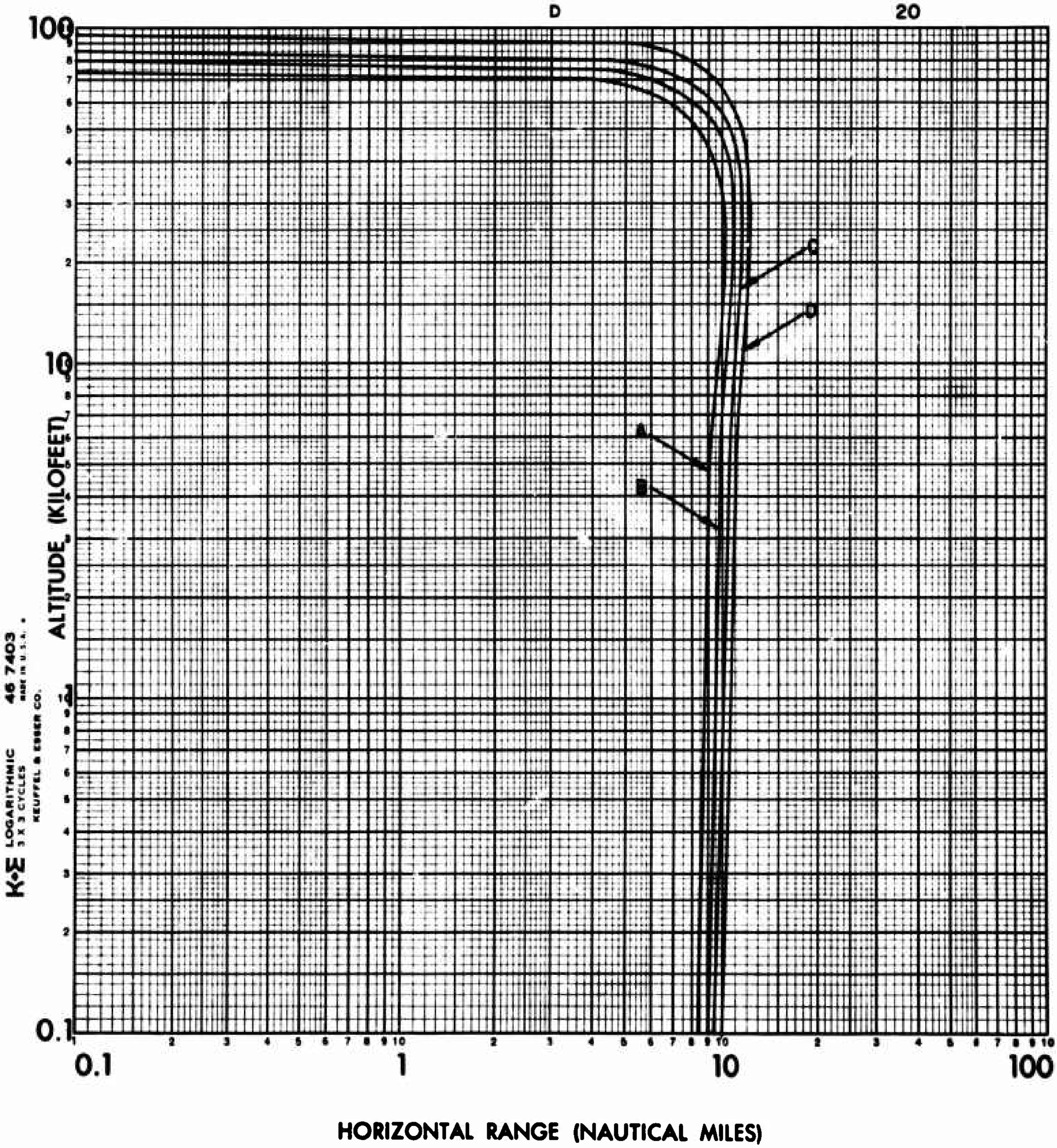


FIGURE 63

FLASHBLINDNESS

DAY MISSION

YIELD: 10 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	

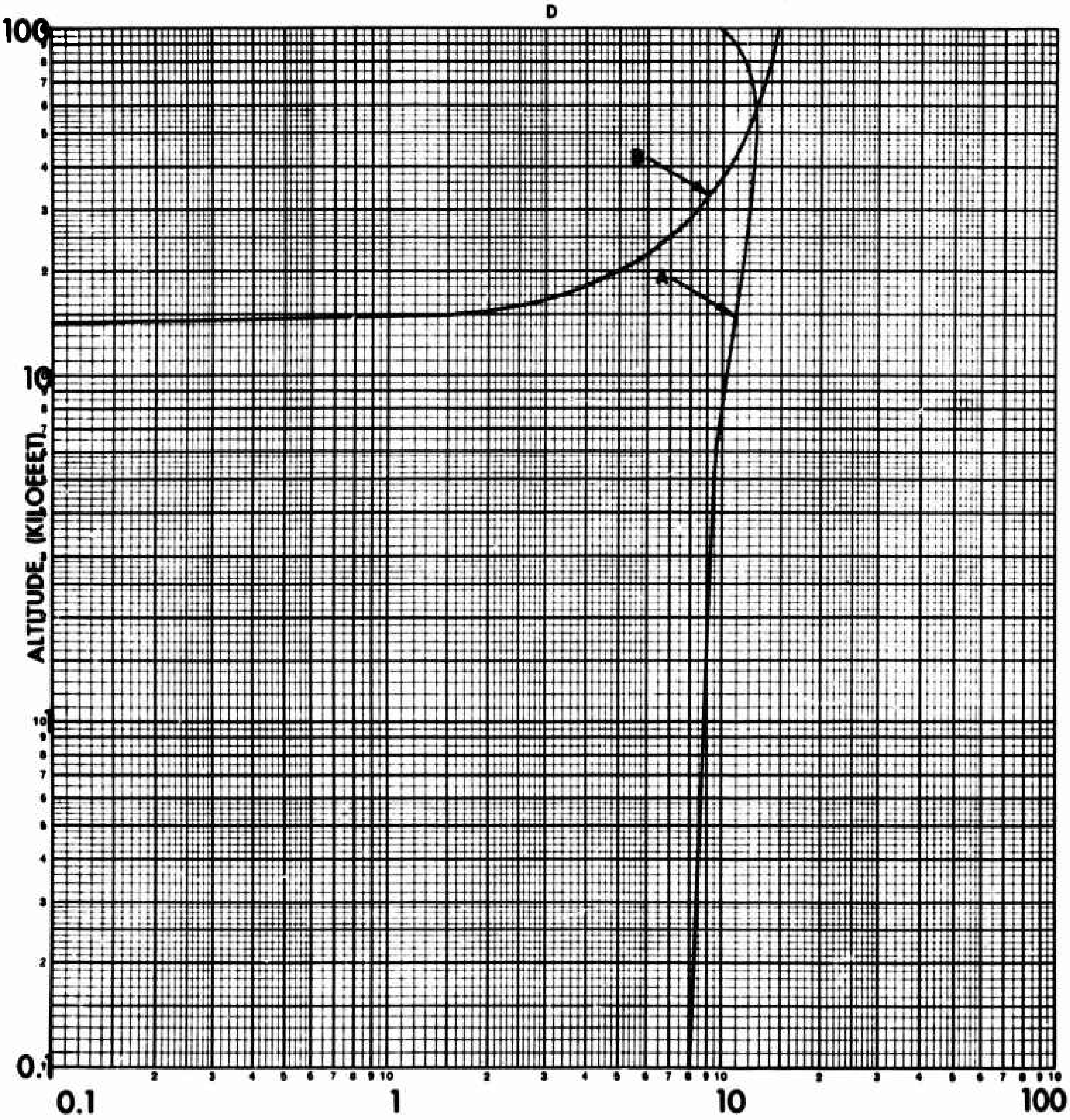


FIGURE 64

FLASHBLINDNESS

DAY MISSION

YIELD: 30 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	5
C	10
D	20

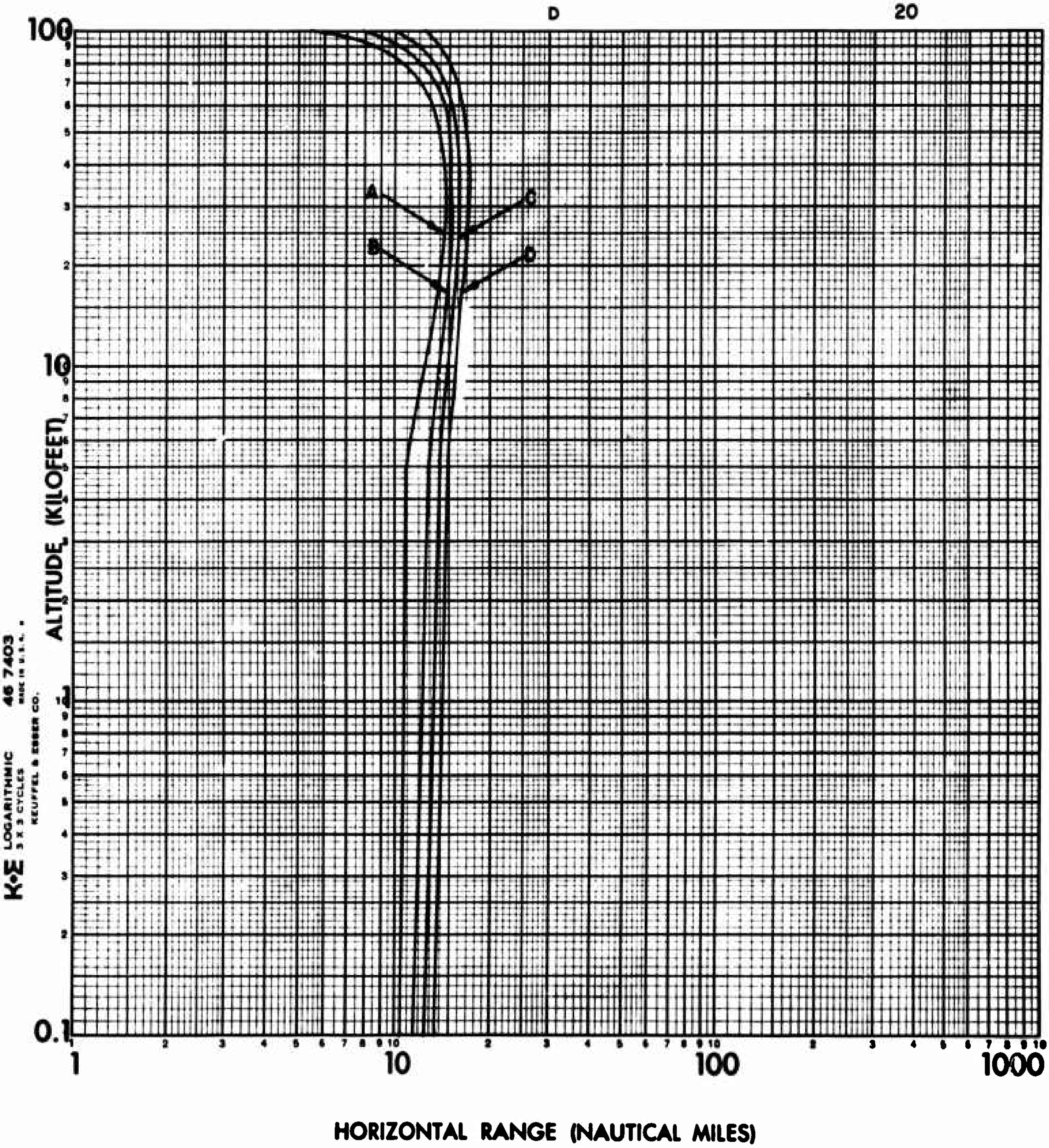


FIGURE 65

FLASHBLINDNESS

DAY MISSION

YIELD: 30 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	

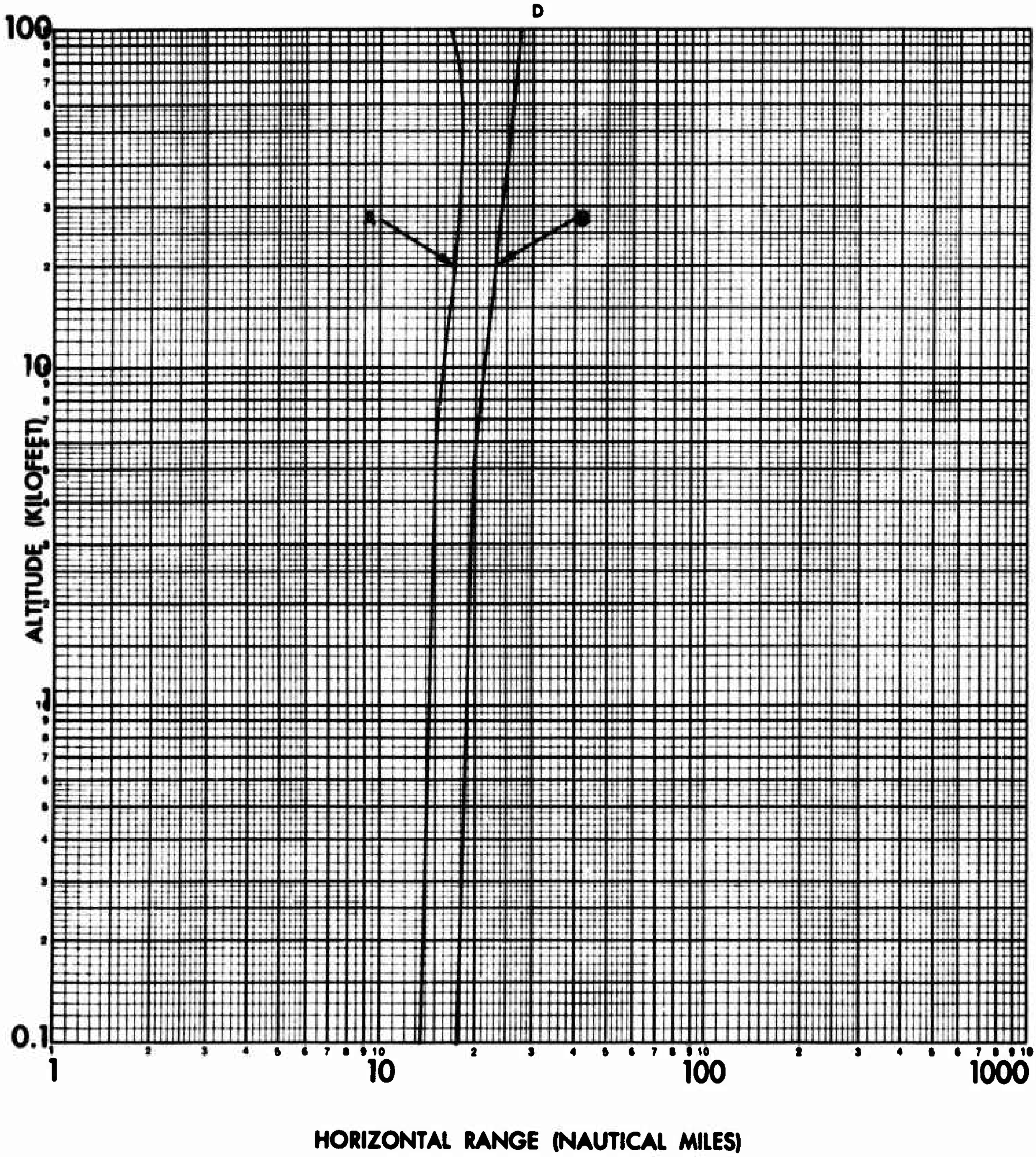


FIGURE 66

FLASHBLINDNESS

DAY MISSION

YIELD: 60 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	5
C	10
D	20

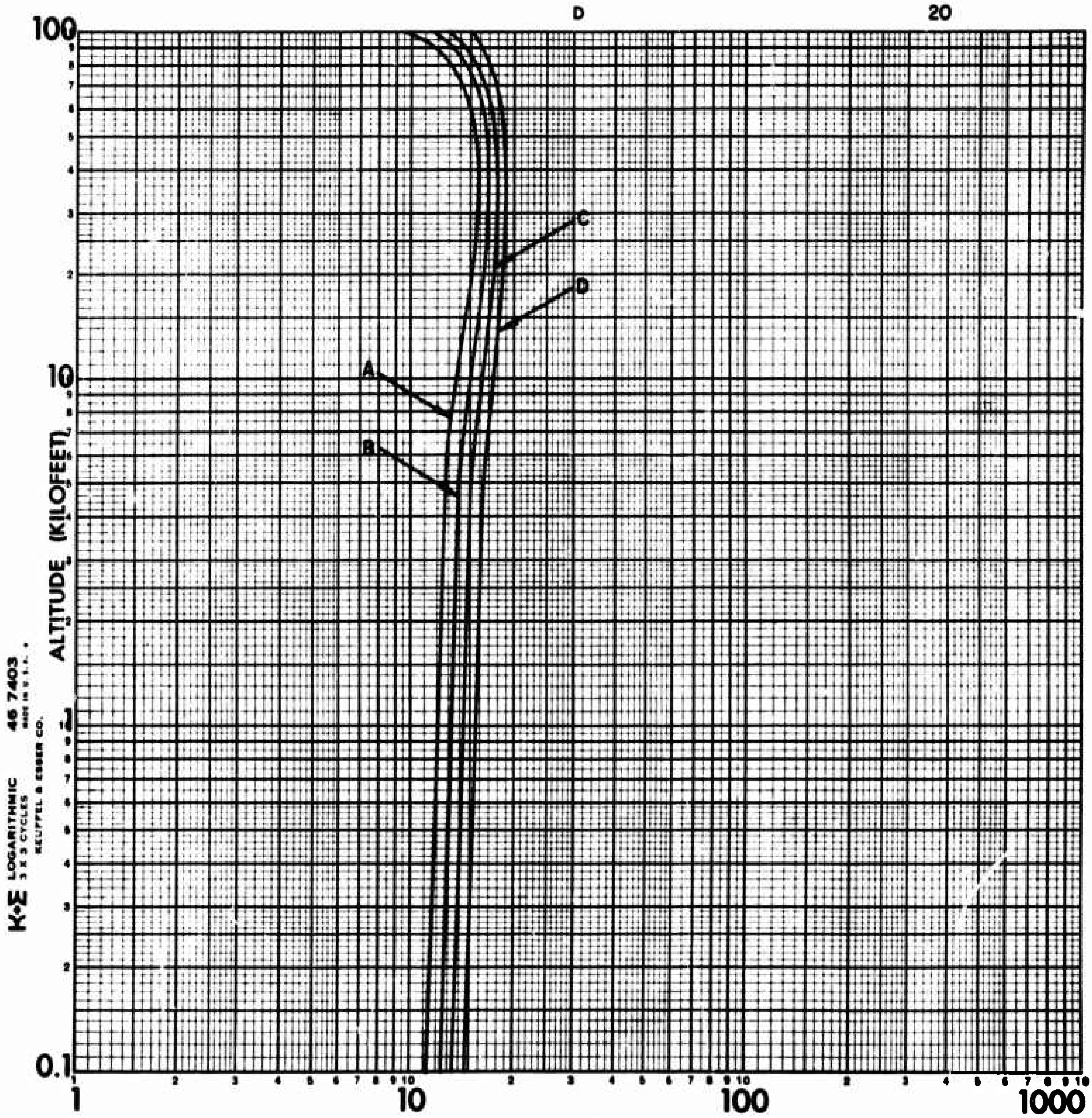


FIGURE 67

FLASHBLINDNESS

DAY MISSION	SYMBOL	BURST ALTITUDE (Kilofeet)
YIELD: 60 KT	A	50
FILTER: NONE	B	100
	C	
	D	

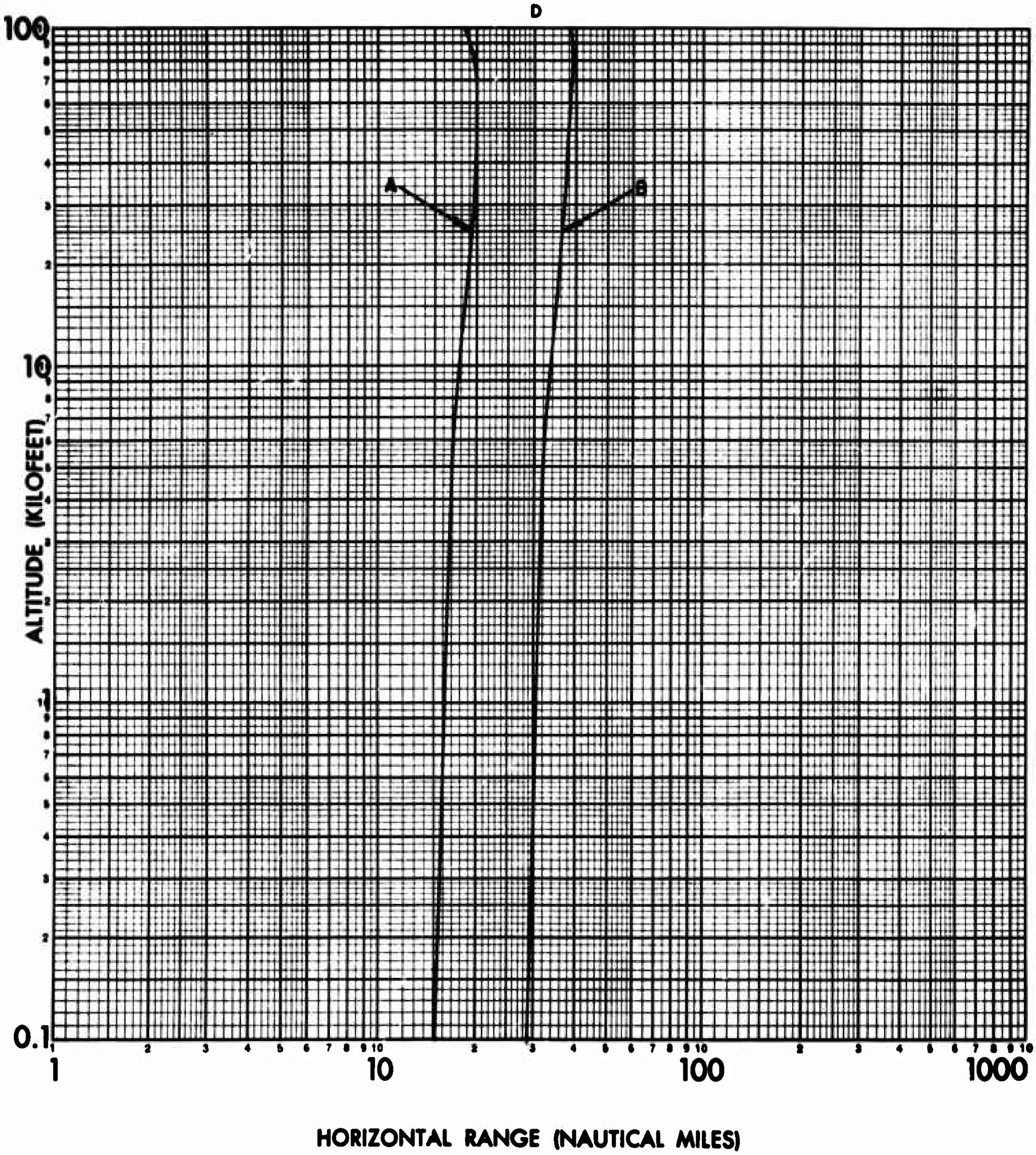


FIGURE 68

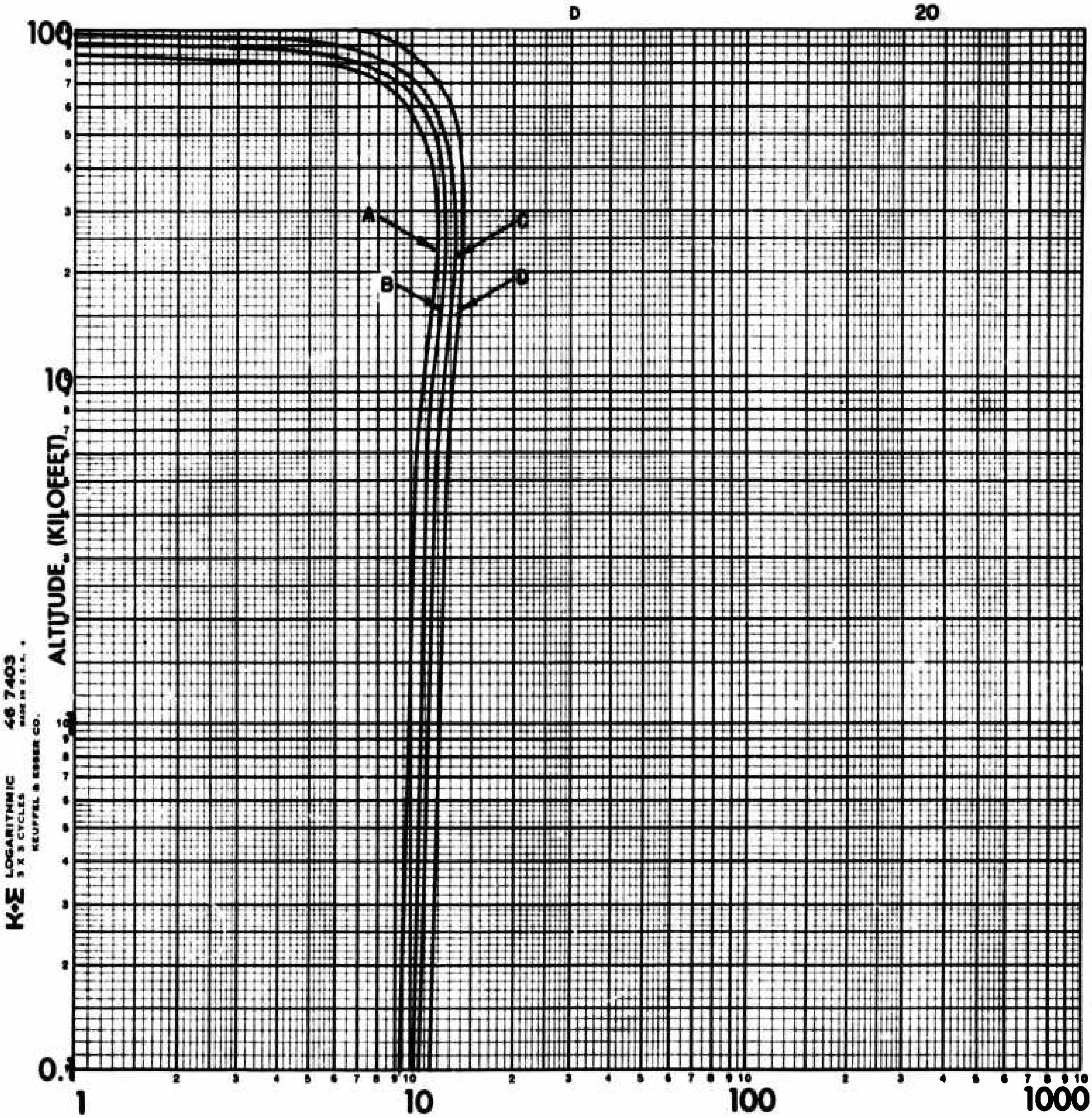
FLASHBLINDNESS

DAY MISSION

YIELD: 200 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1.5
B	5
C	10
D	20



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 69

FLASHBLINDNESS

DAY MISSION

YIELD: 200 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	

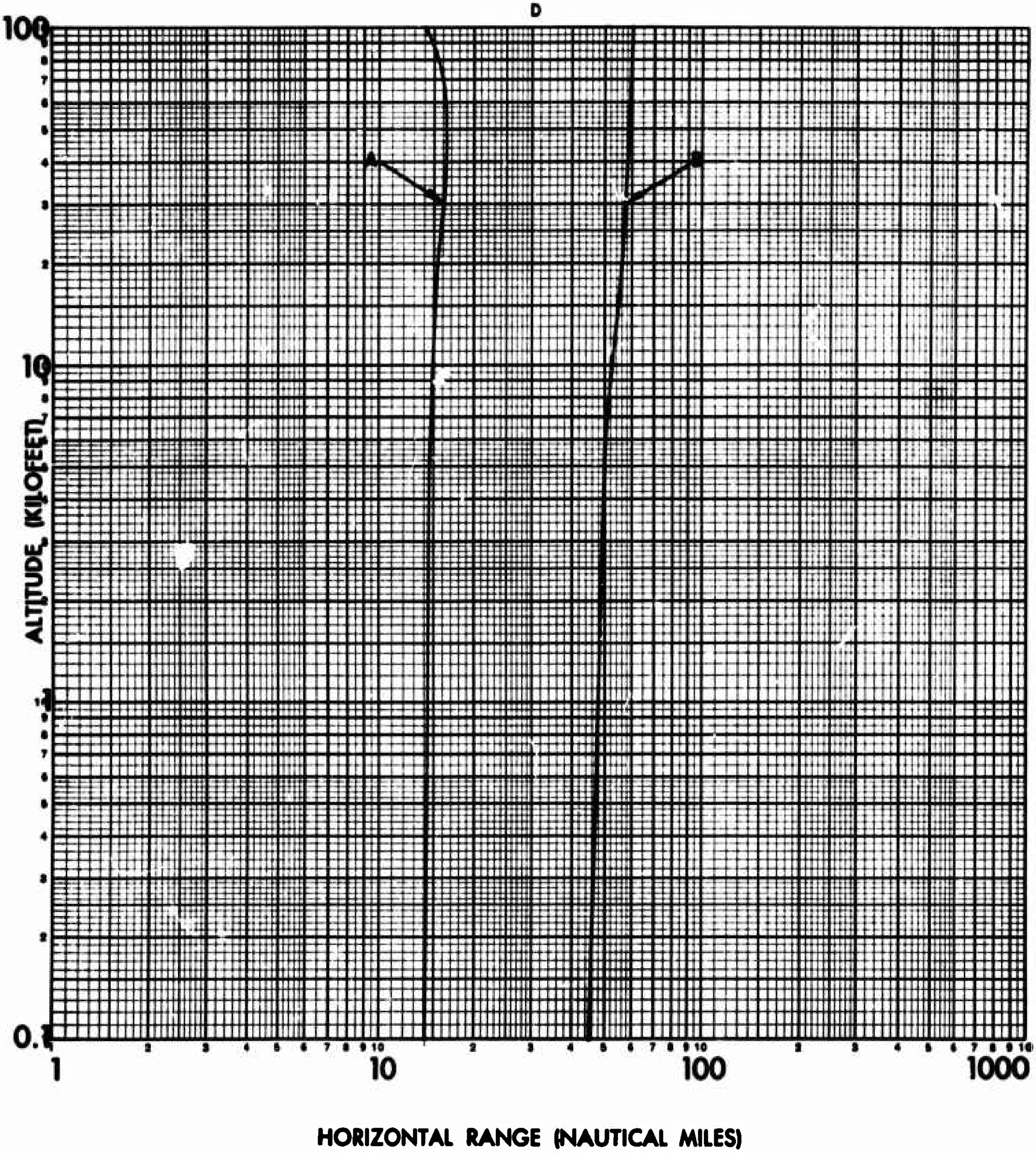


FIGURE 70

FLASHBLINDNESS

DAY MISSION

YIELD: 440 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1.5
B	5
C	10
D	20

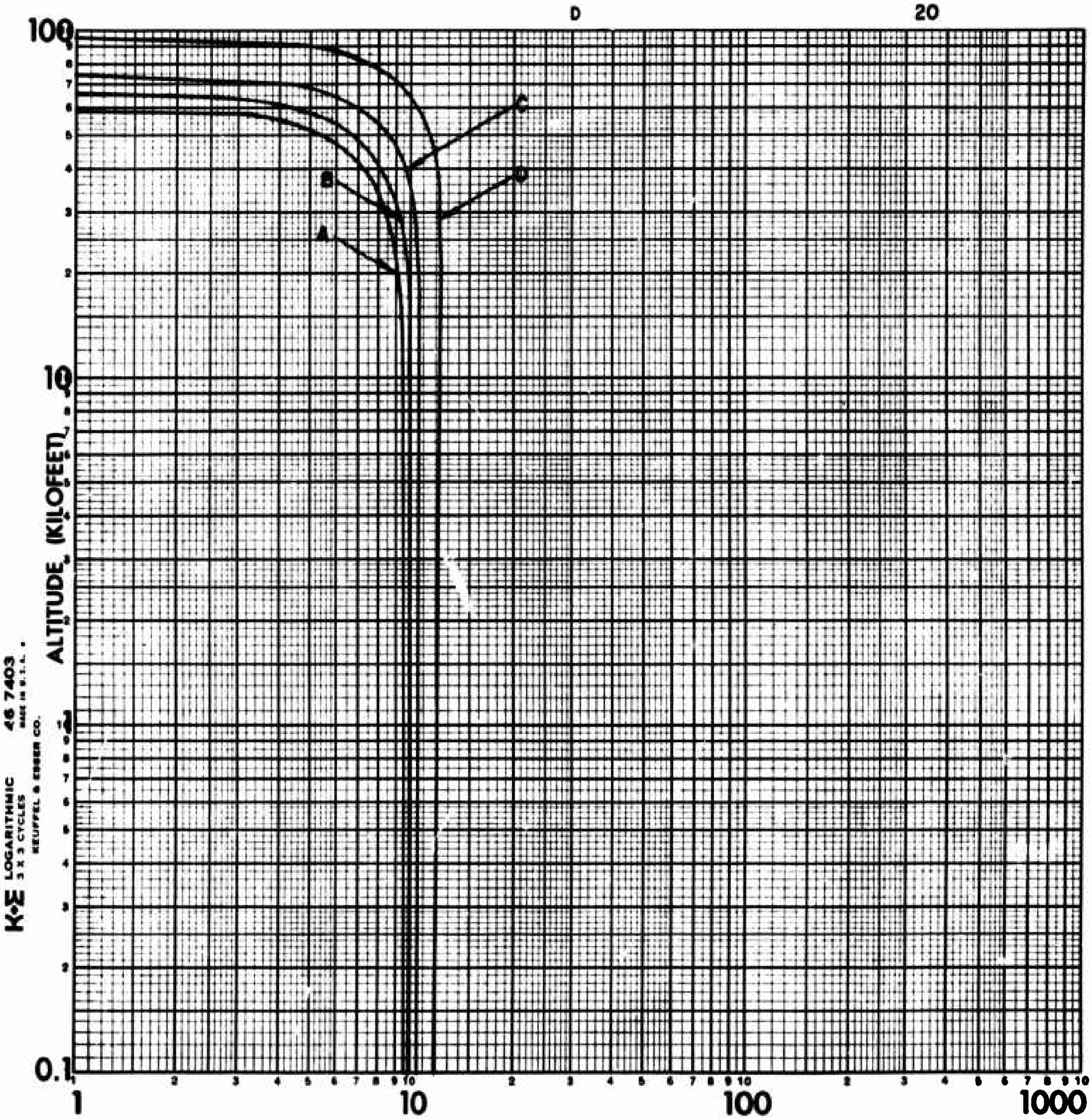


FIGURE 71

FLASHBLINDNESS

DAY MISSION

YIELD: 440 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	

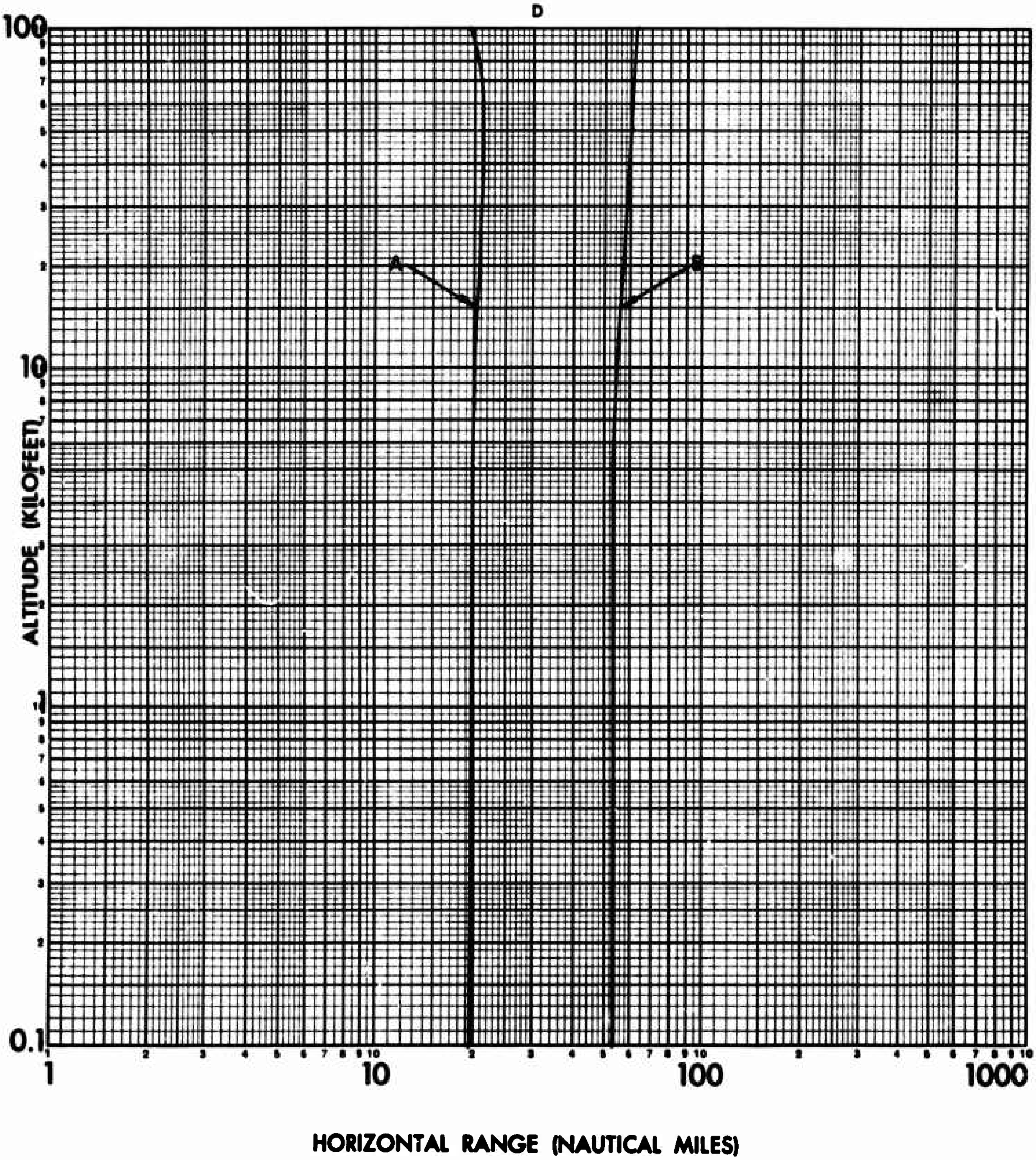


FIGURE 72

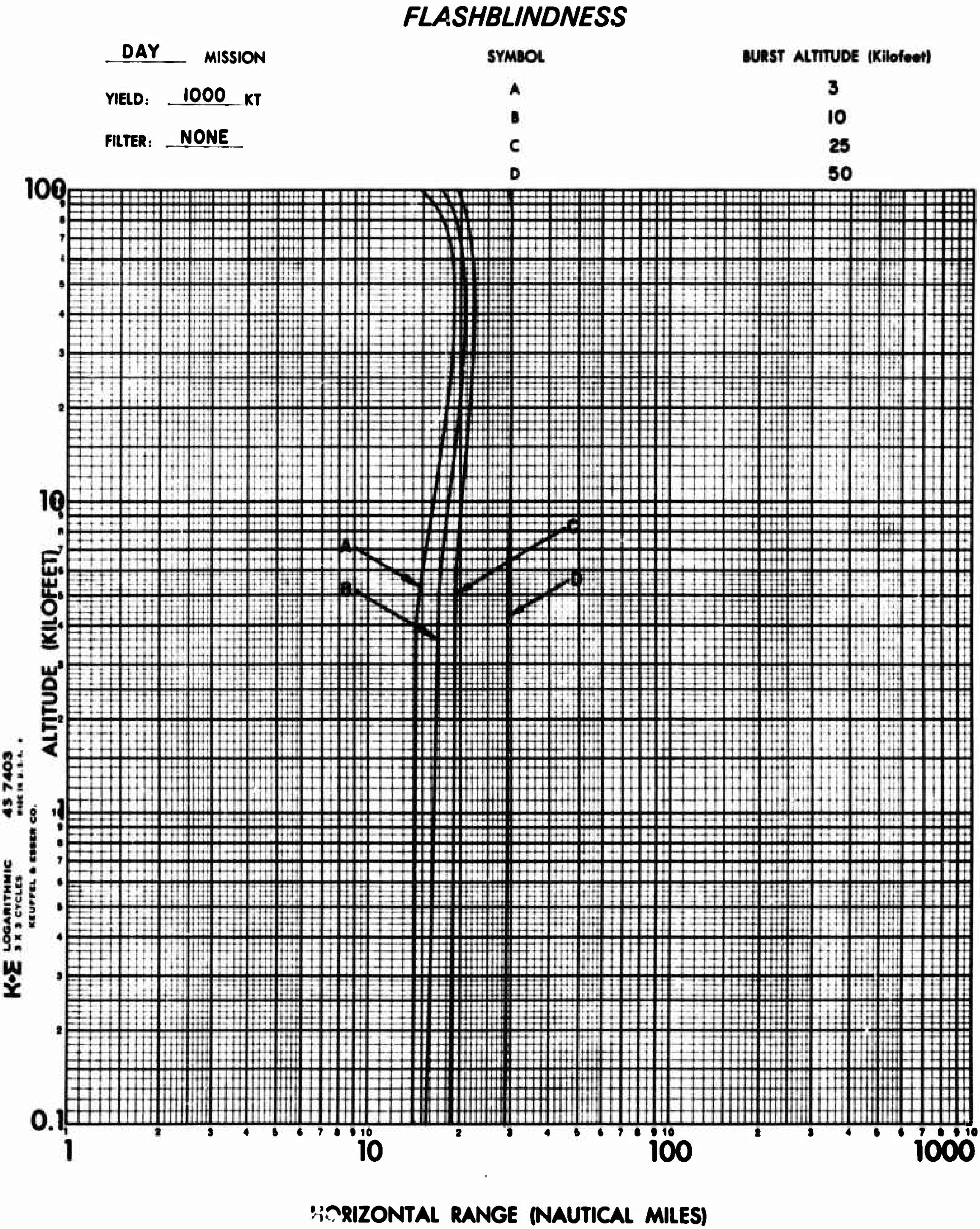

FLASHBLINDNESS
DAY MISSION
YIELD: 1000 KT
FILTER: NONE
SYMBOL
BURST ALTITUDE (Kilofeet)
A 3
B 10
C 25
D 50
ALTITUDE (KILOFEET)
HORIZONTAL RANGE (NAUTICAL MILES)
100
10
1
0.1
1
10
100
1000
A
B
C
D
K+E LOGARITHMIC 3 X 3 CYCLES
KEUFFEL & ESSER CO.
45 7403

FIGURE 73

FLASHBLINDNESS

DAY MISSION

YIELD: 3800 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	4
B	10
C	25
D	50

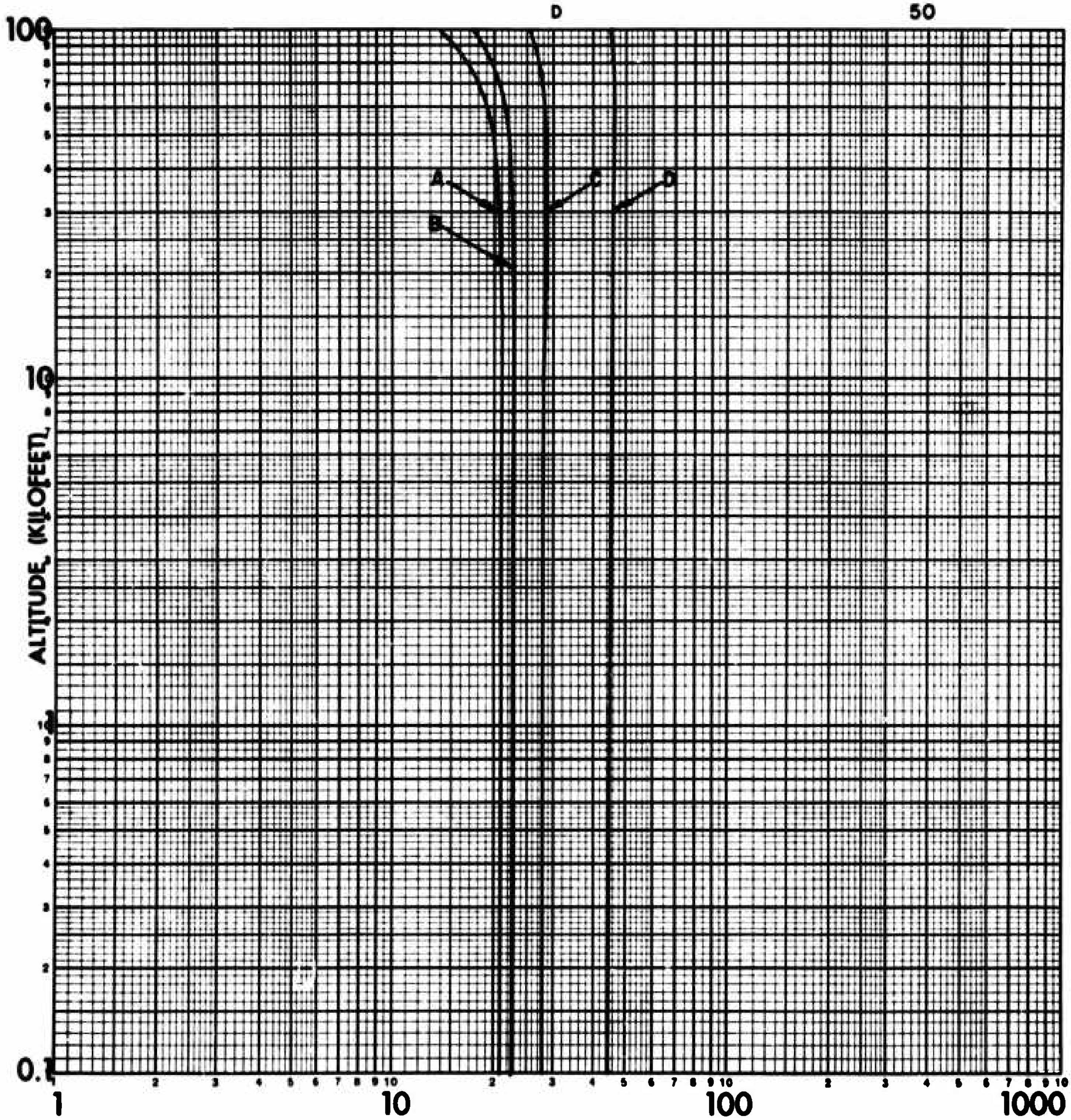


FIGURE 74

FLASHBLINDNESS

DAY MISSION

YIELD: 9000 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	5
B	10
C	25
D	50

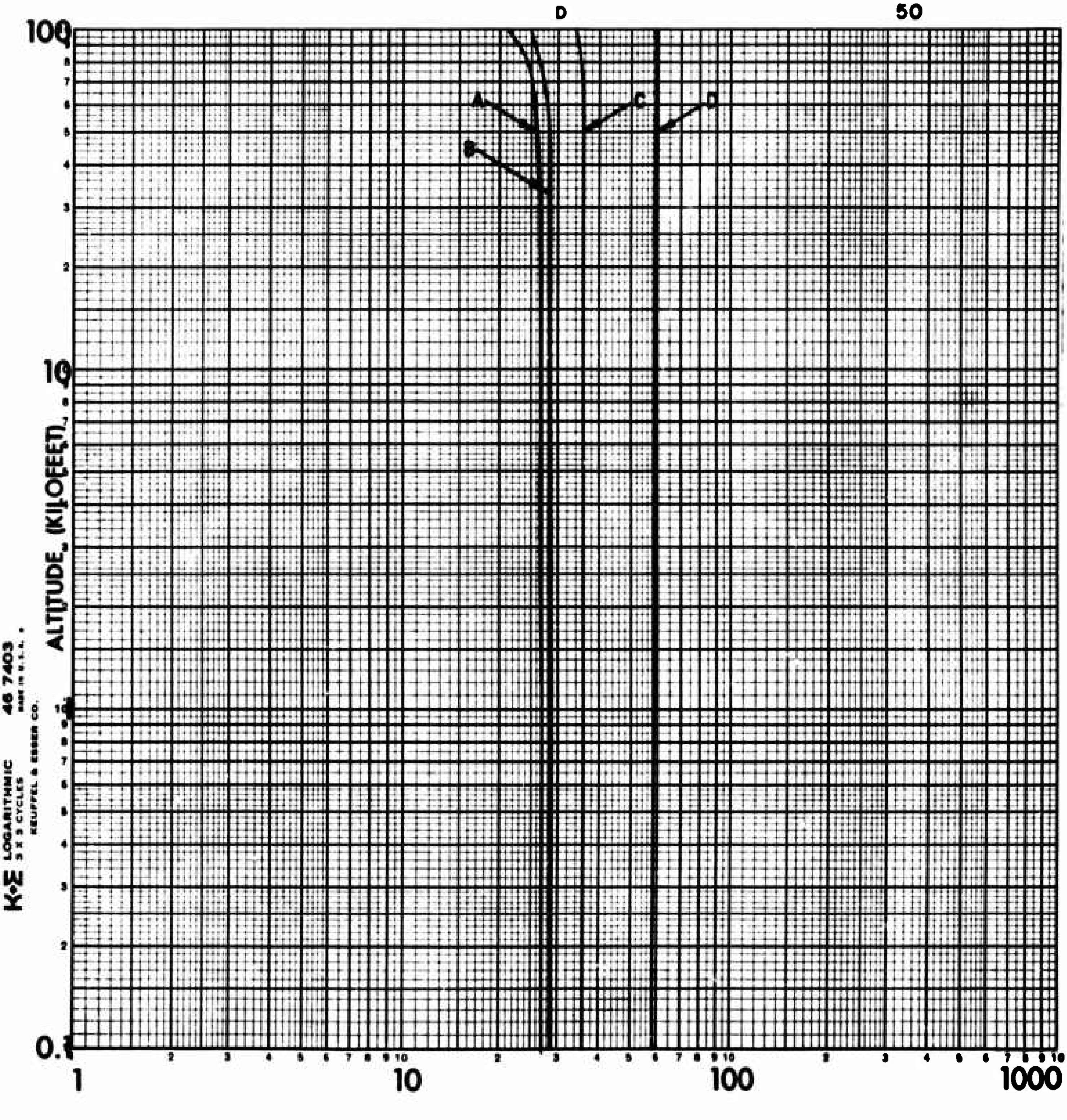


FIGURE 75

FLASHBLINDNESS

DAY MISSION

YIELD: 23000 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	6
B	10
C	25
D	50

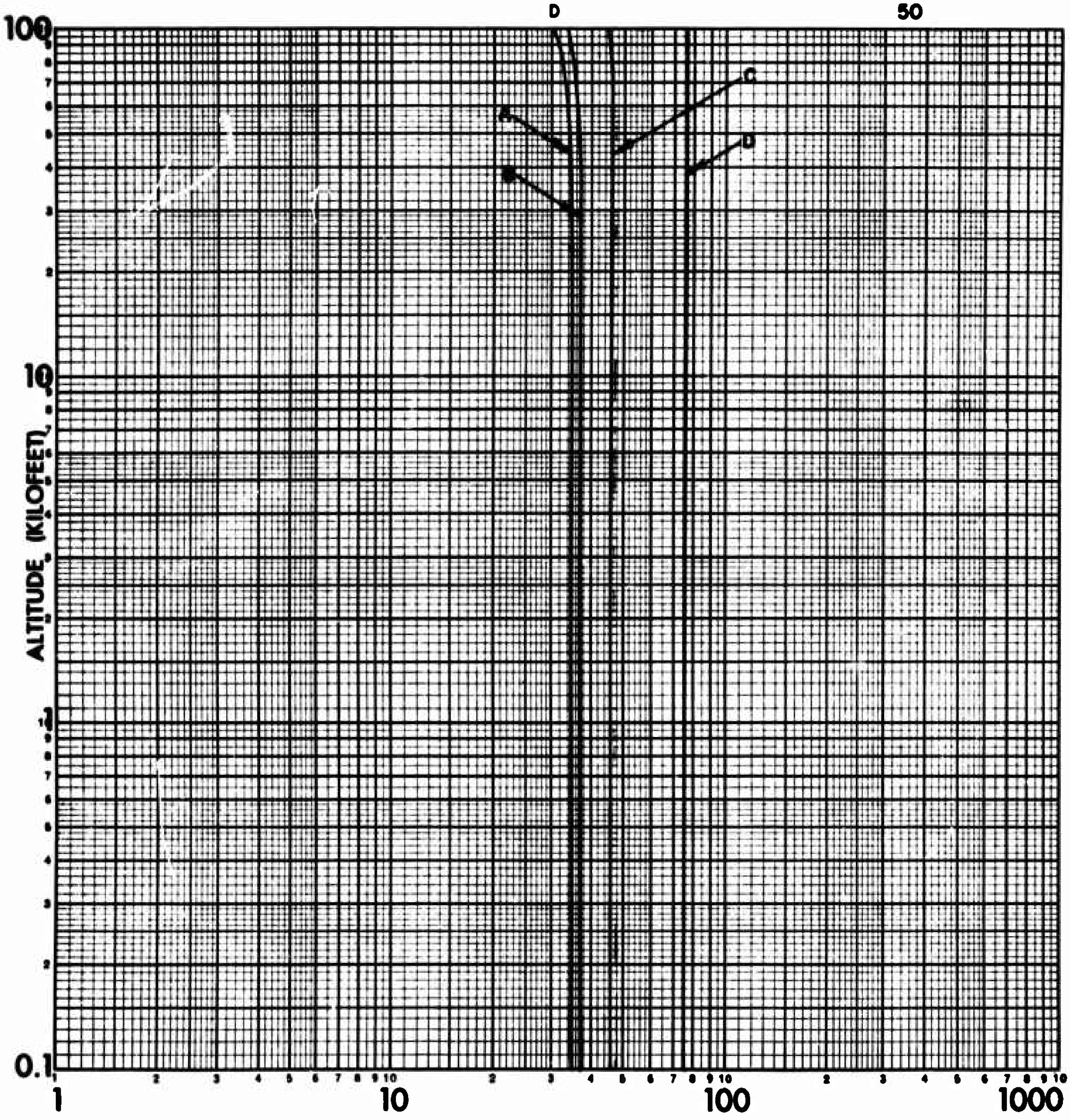


FIGURE 76

FLASHBLINDNESS SAFE SEPARATION ENVELOPES

NIGHT MISSION

FLASHBLINDNESS

NIGHT MISSION

YIELD: 0.02 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	10
C	25
D	50

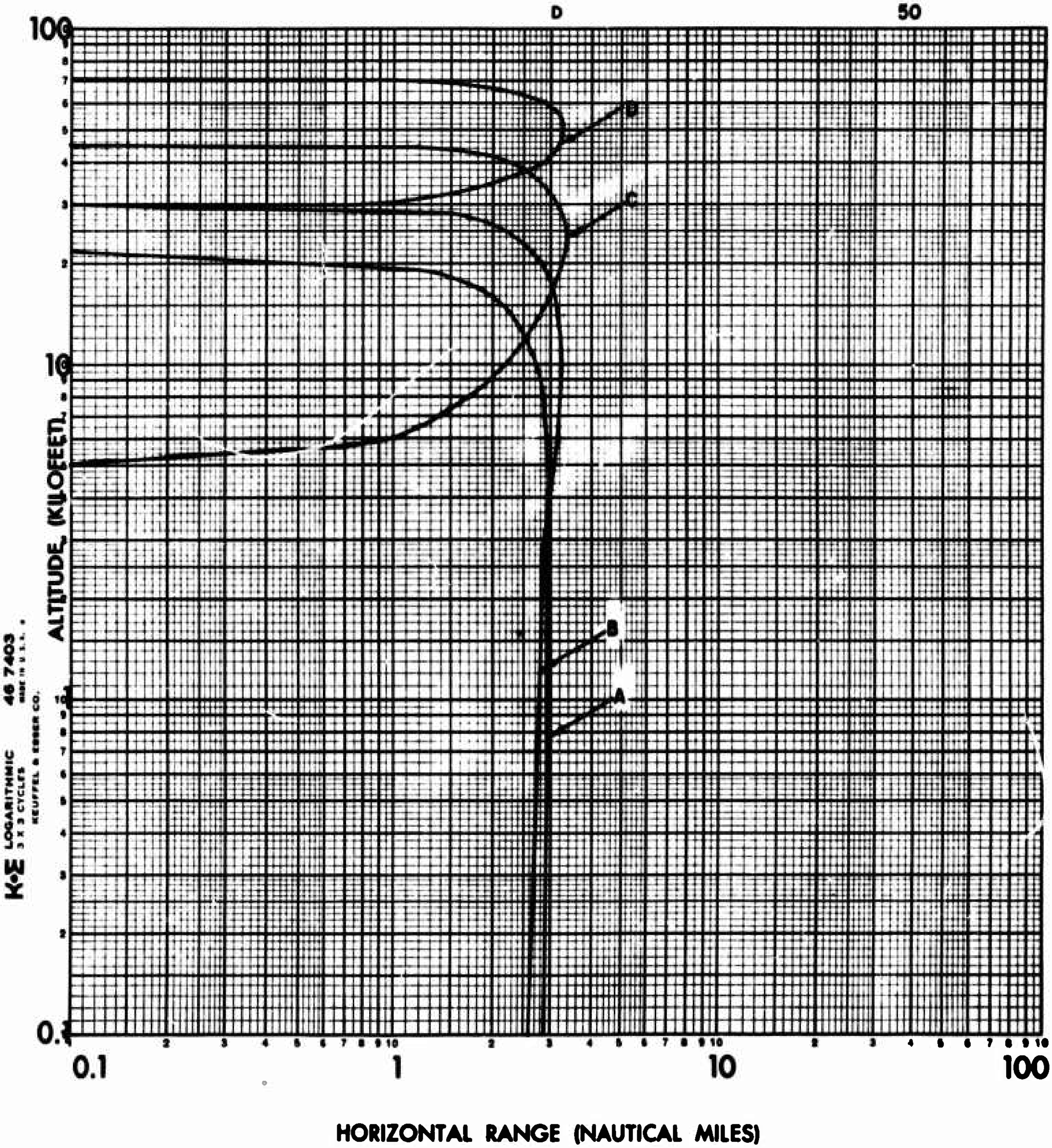


FIGURE 77

FLASHBLINDNESS

NIGHT MISSION

YIELD: 0.02 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	75
B	100
C	
D	

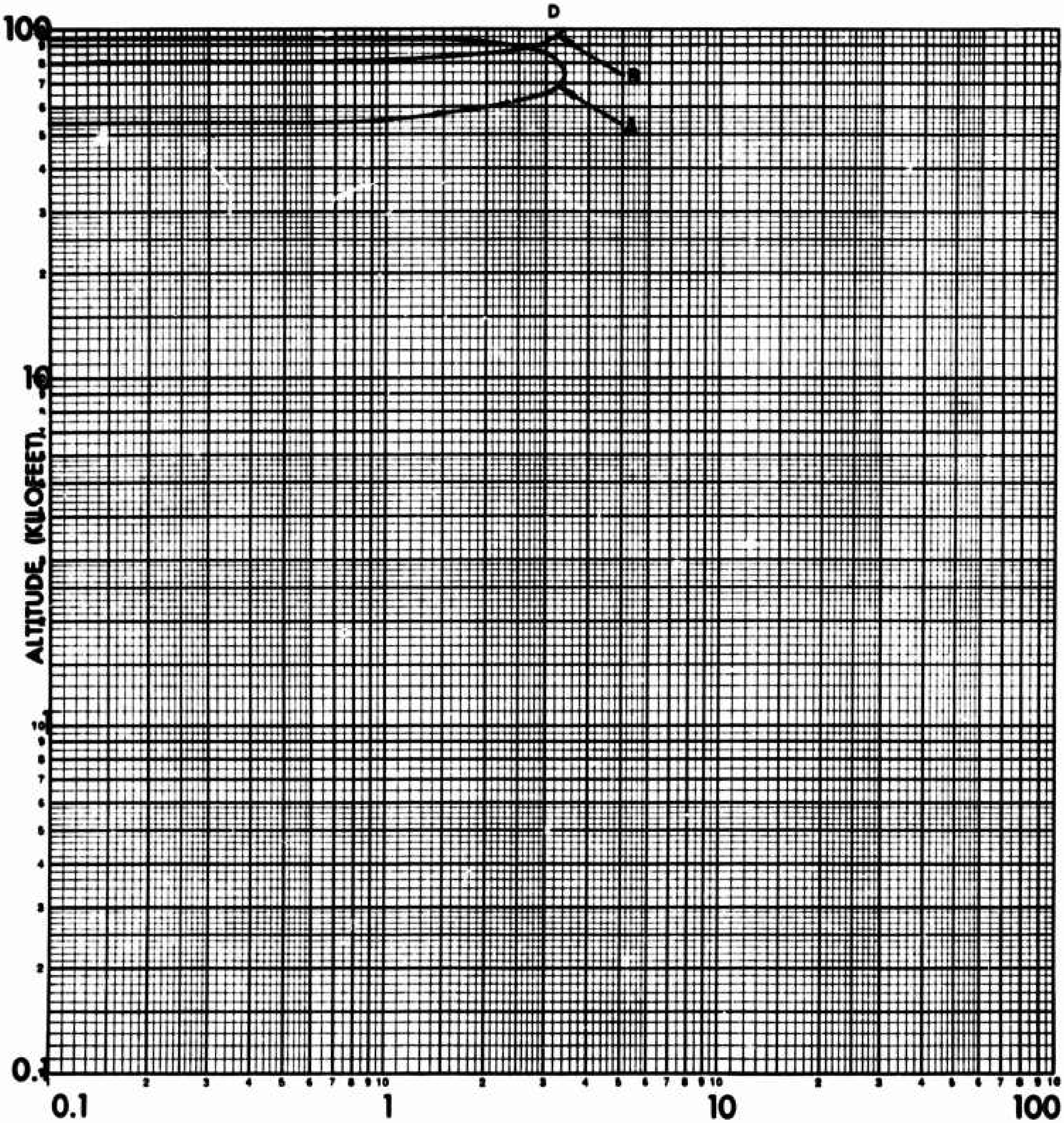


FIGURE 78

FLASHBLINDNESS

NIGHT MISSION

YIELD: 0.6 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	5
C	10
D	20

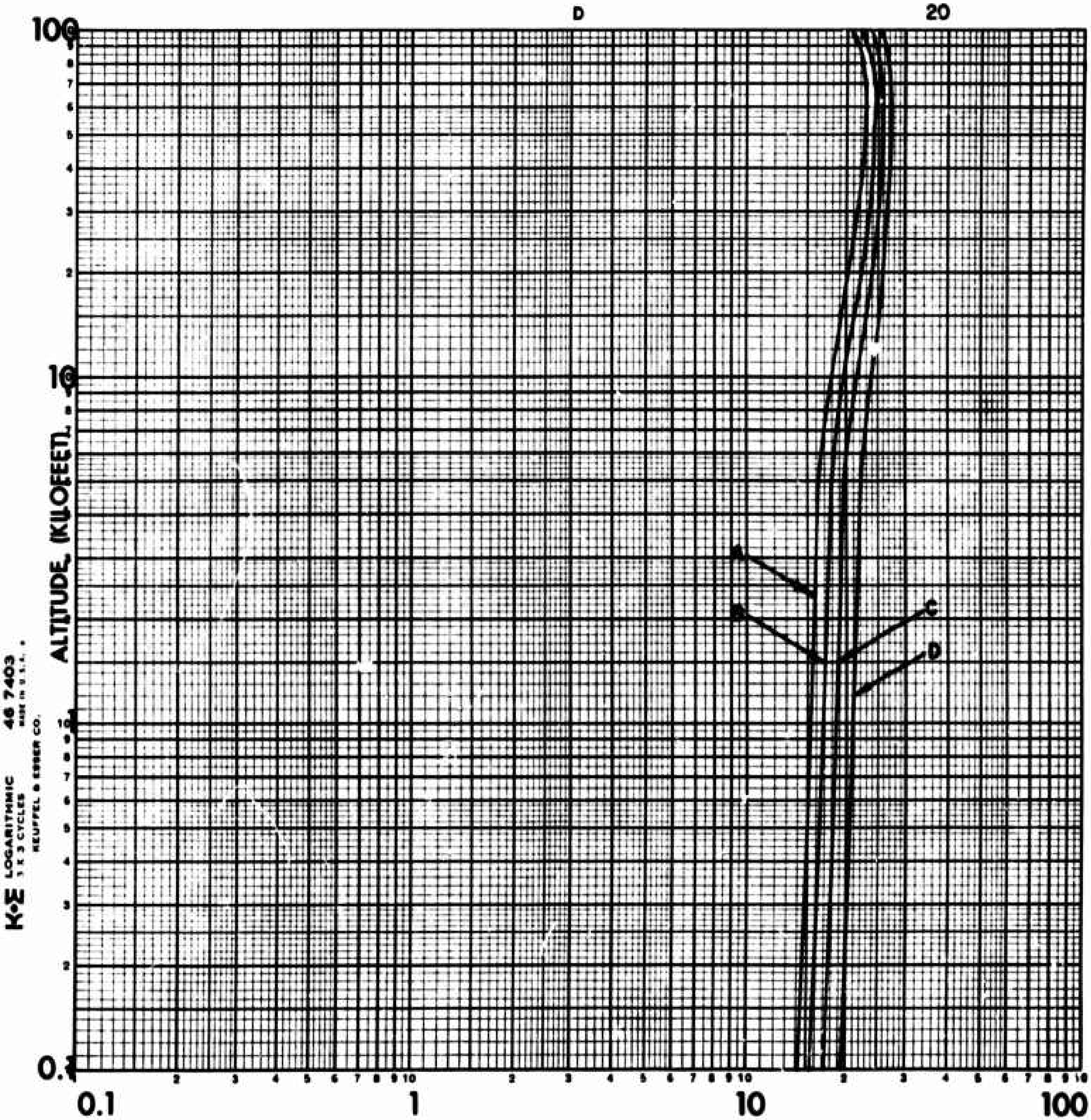


FIGURE 79

FLASHBLINDNESS

NIGHT MISSION

YIELD: 0.6 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	

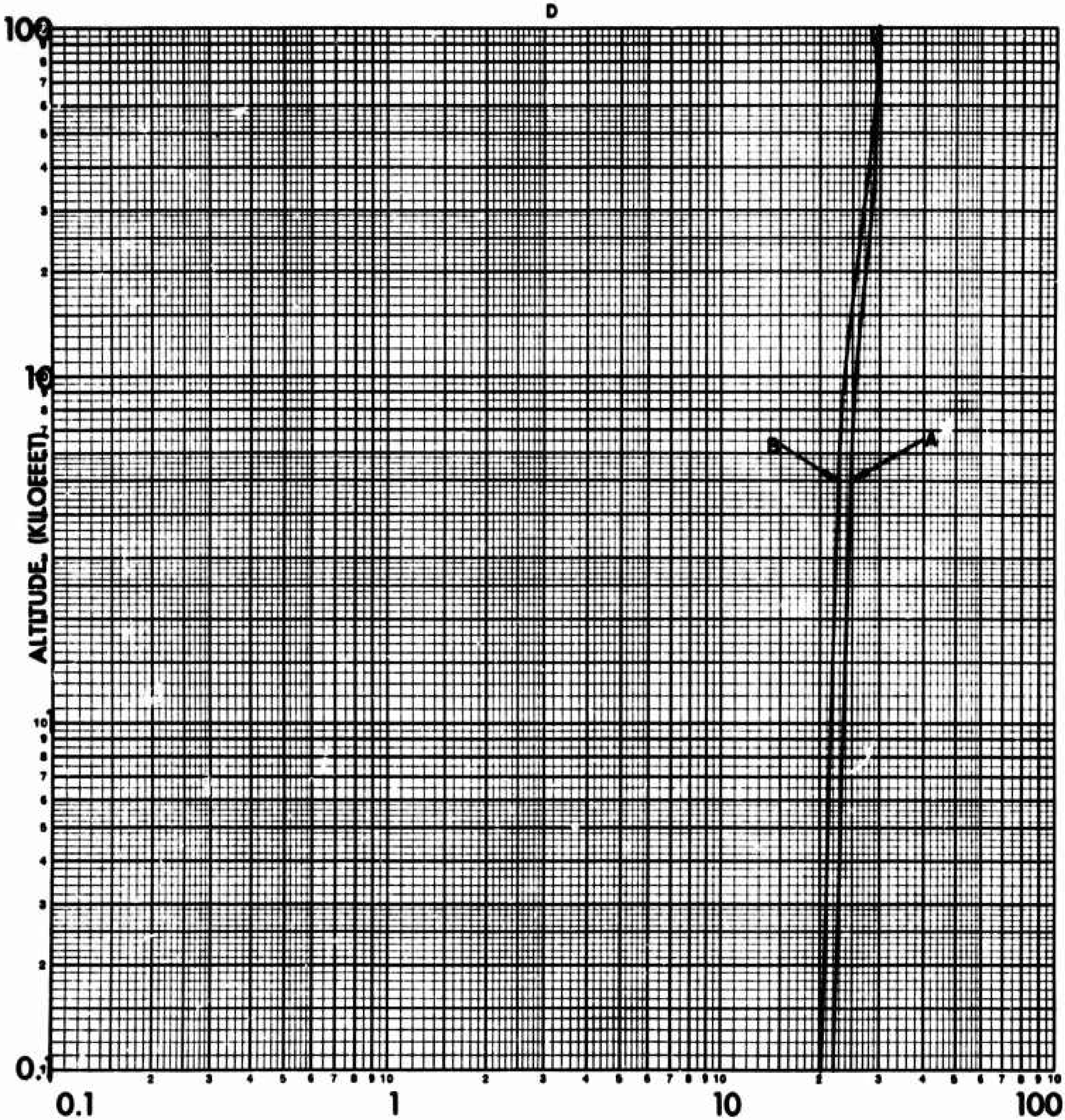


FIGURE 80

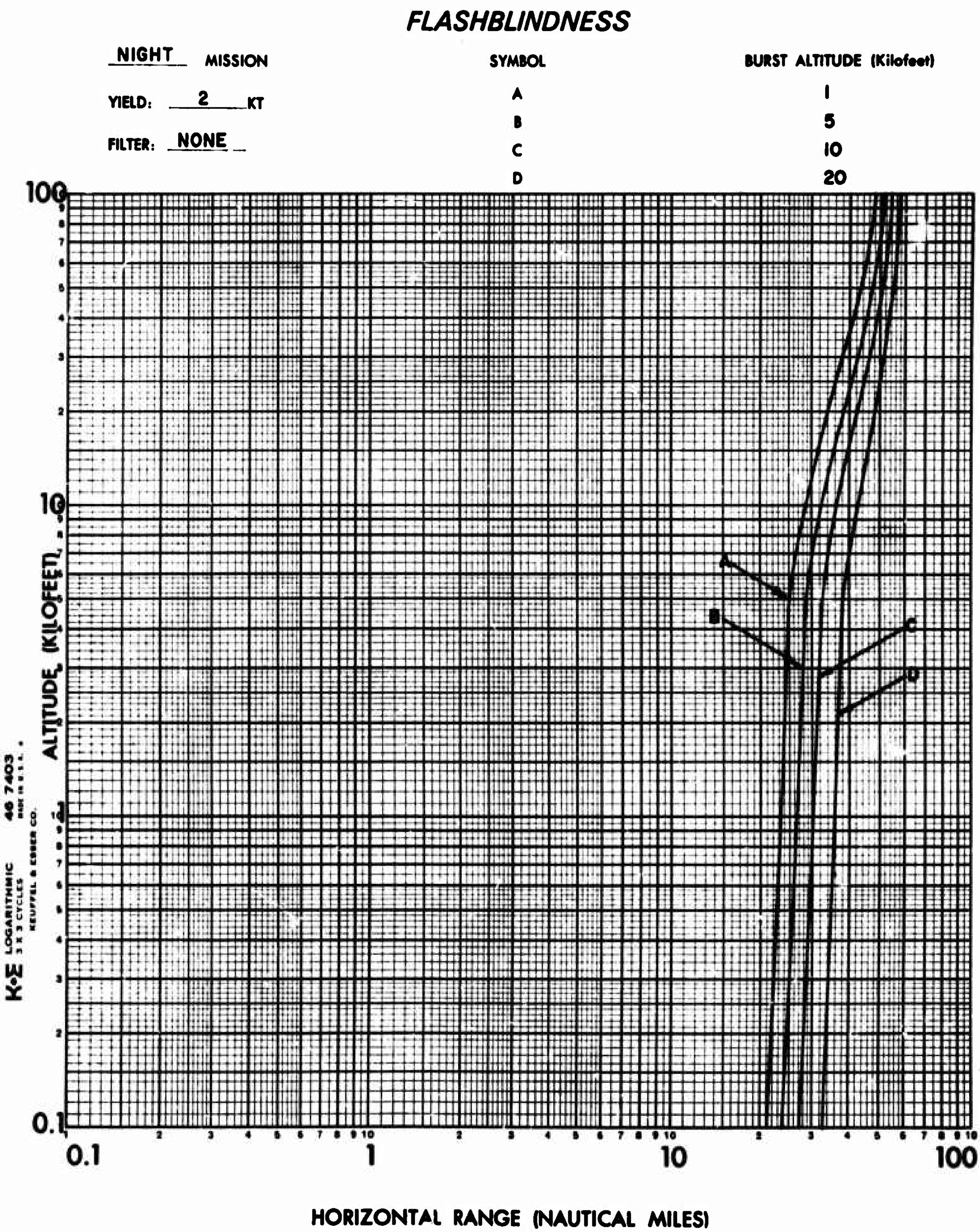

FLASHBLINDNESS
NIGHT MISSION
YIELD: 2 KT
FILTER: NONE
SYMBOL
A
B
C
D
BURST ALTITUDE (Kilofeet)
1
5
10
20
ALTITUDE (KILOFEET)
100
10
1
0.1
A
B
C
D
0.1
1
10
100
HORIZONTAL RANGE (NAUTICAL MILES)
K+E LOGARITHMIC 46 7403
3 X 3 CYCLES
KEUFFEL & ESSER CO.

FIGURE 81

FLASHBLINDNESS

NIGHT MISSION

YIELD: 2 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	

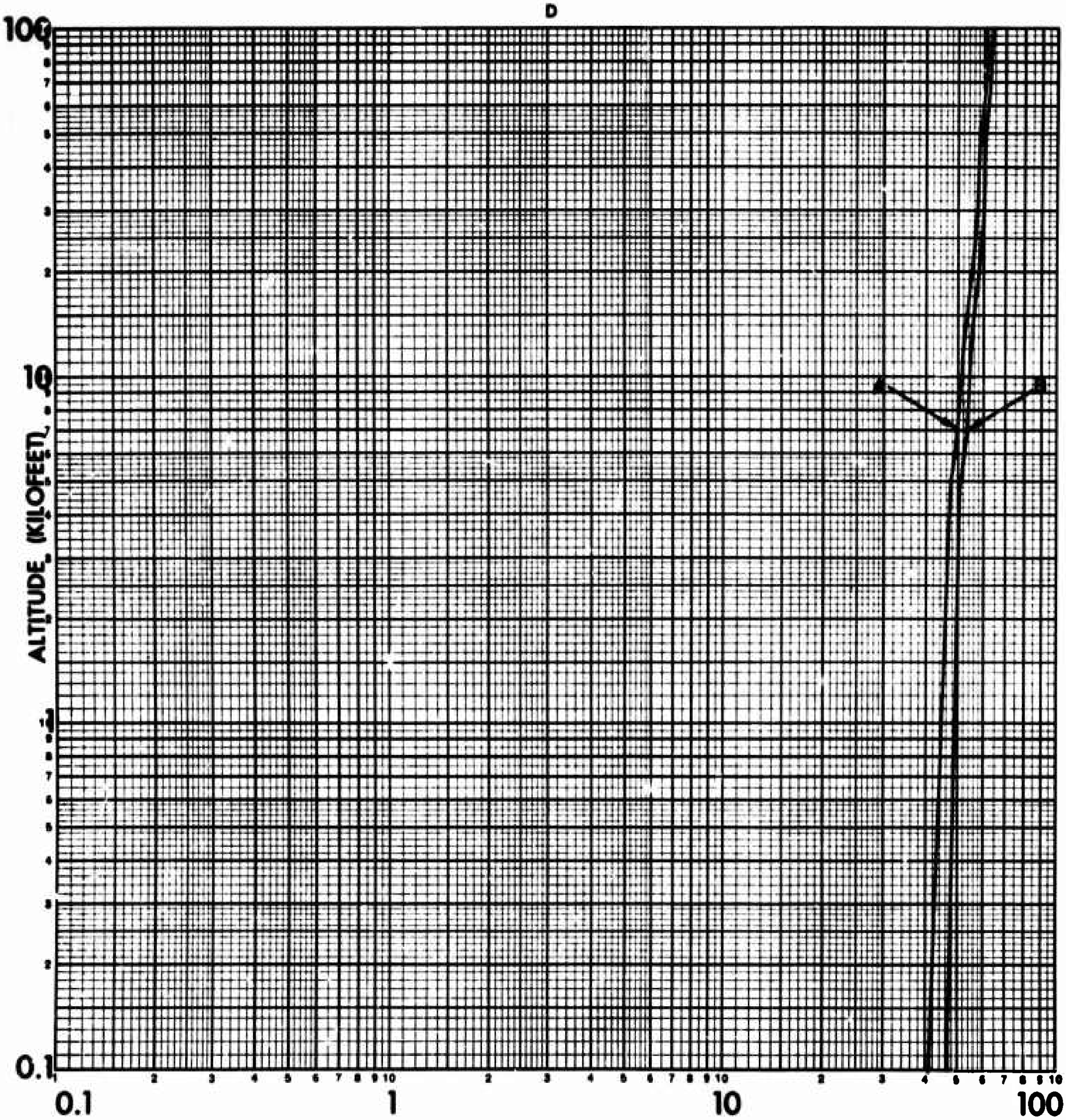


FIGURE 82

FLASHBLINDNESS

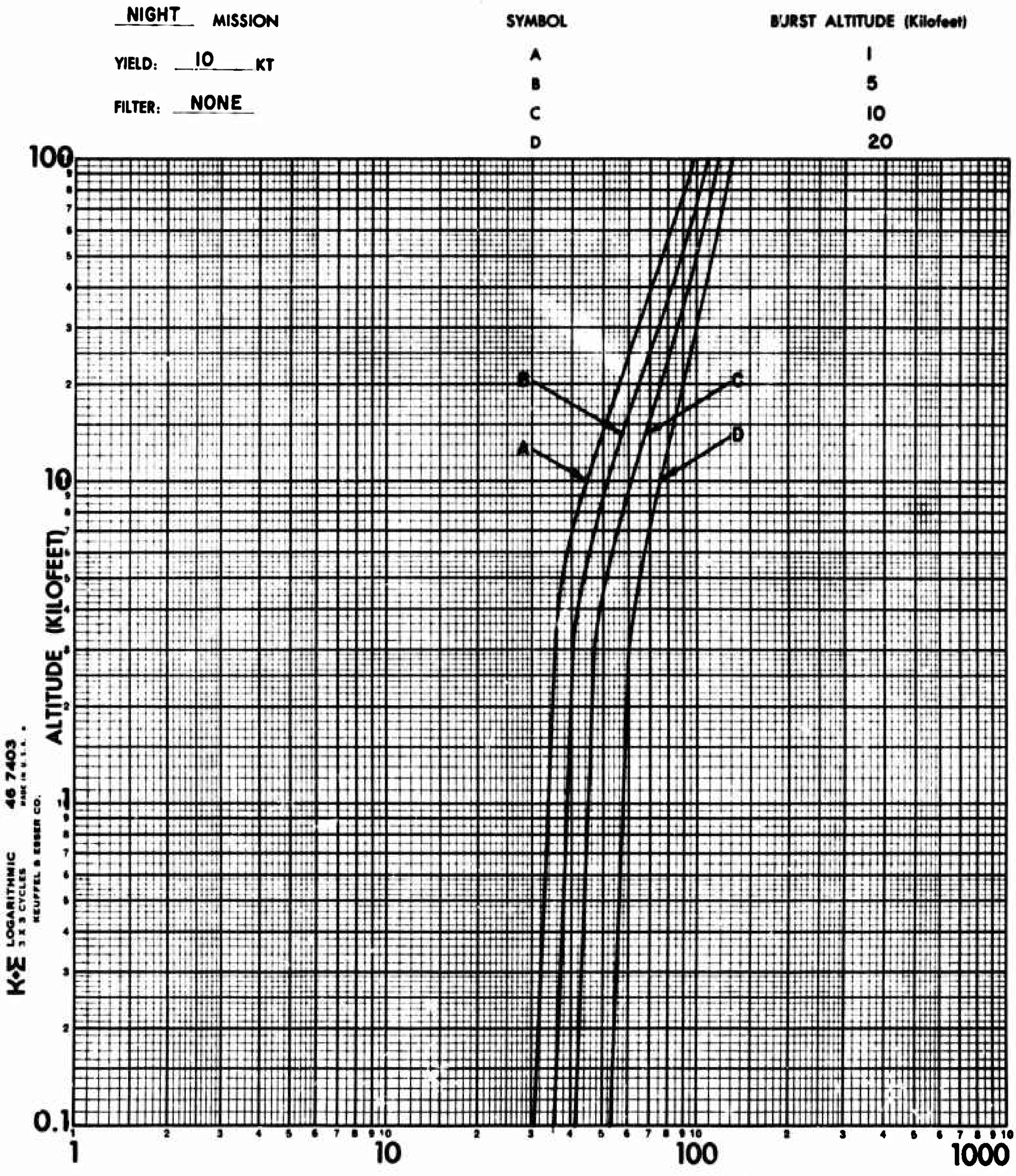


FIGURE 83

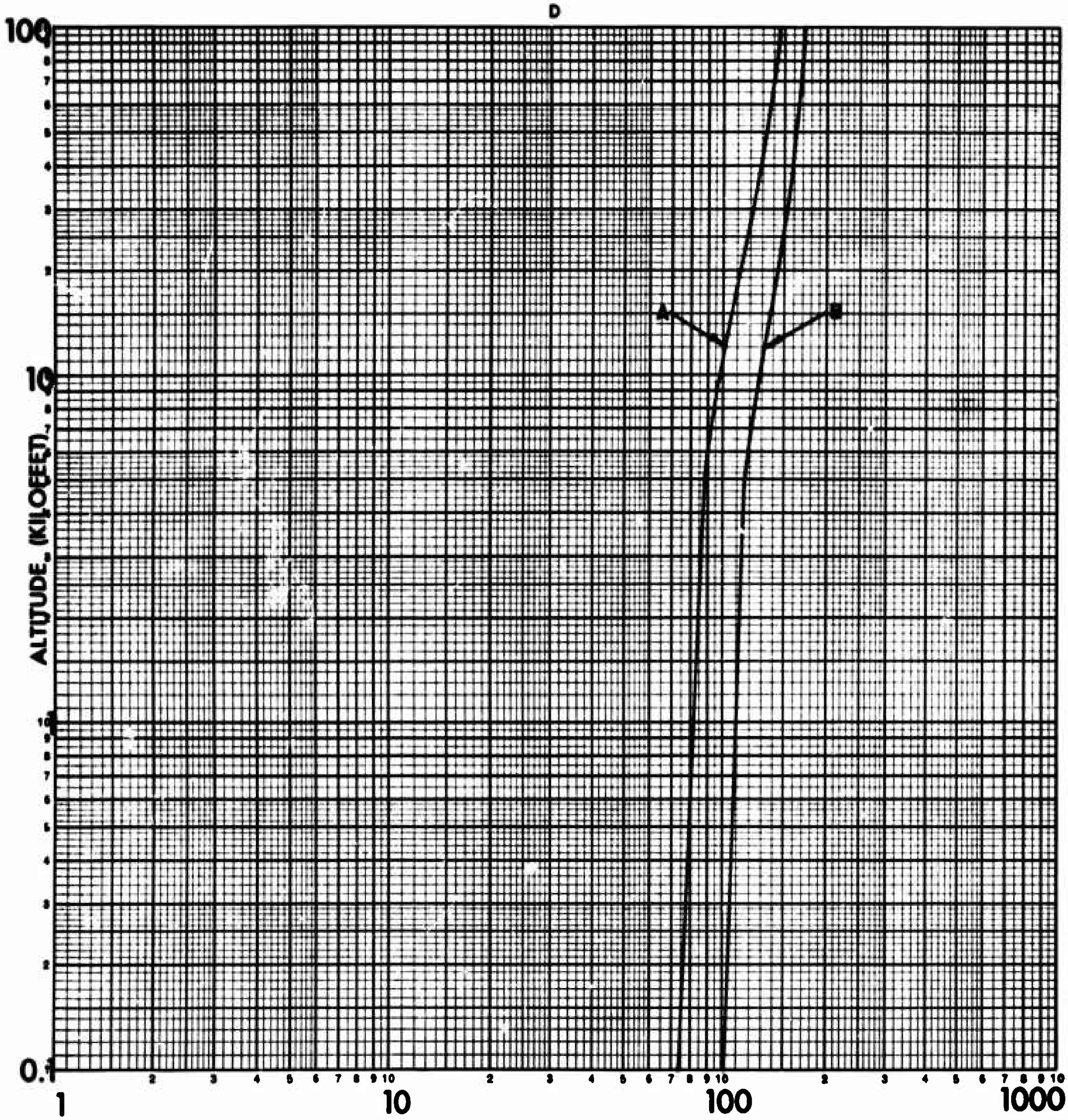
FLASHBLINDNESS

NIGHT MISSION

YIELD: 10 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 84

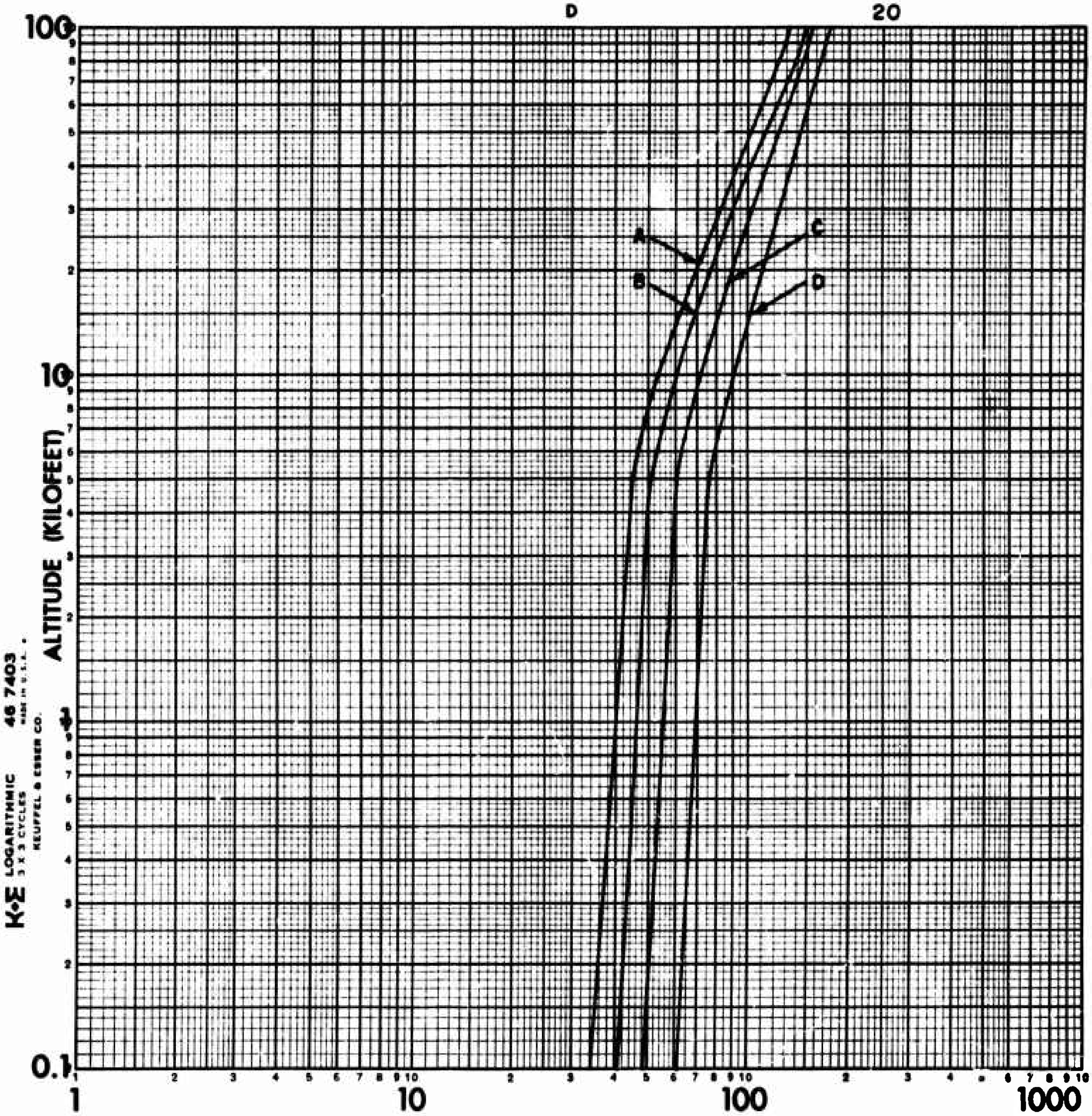
FLASHBLINDNESS

NIGHT MISSION

YIELD: 30 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	5
C	10
D	20



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 85

FLASHBLINDNESS

NIGHT MISSION

YIELD: 30 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	

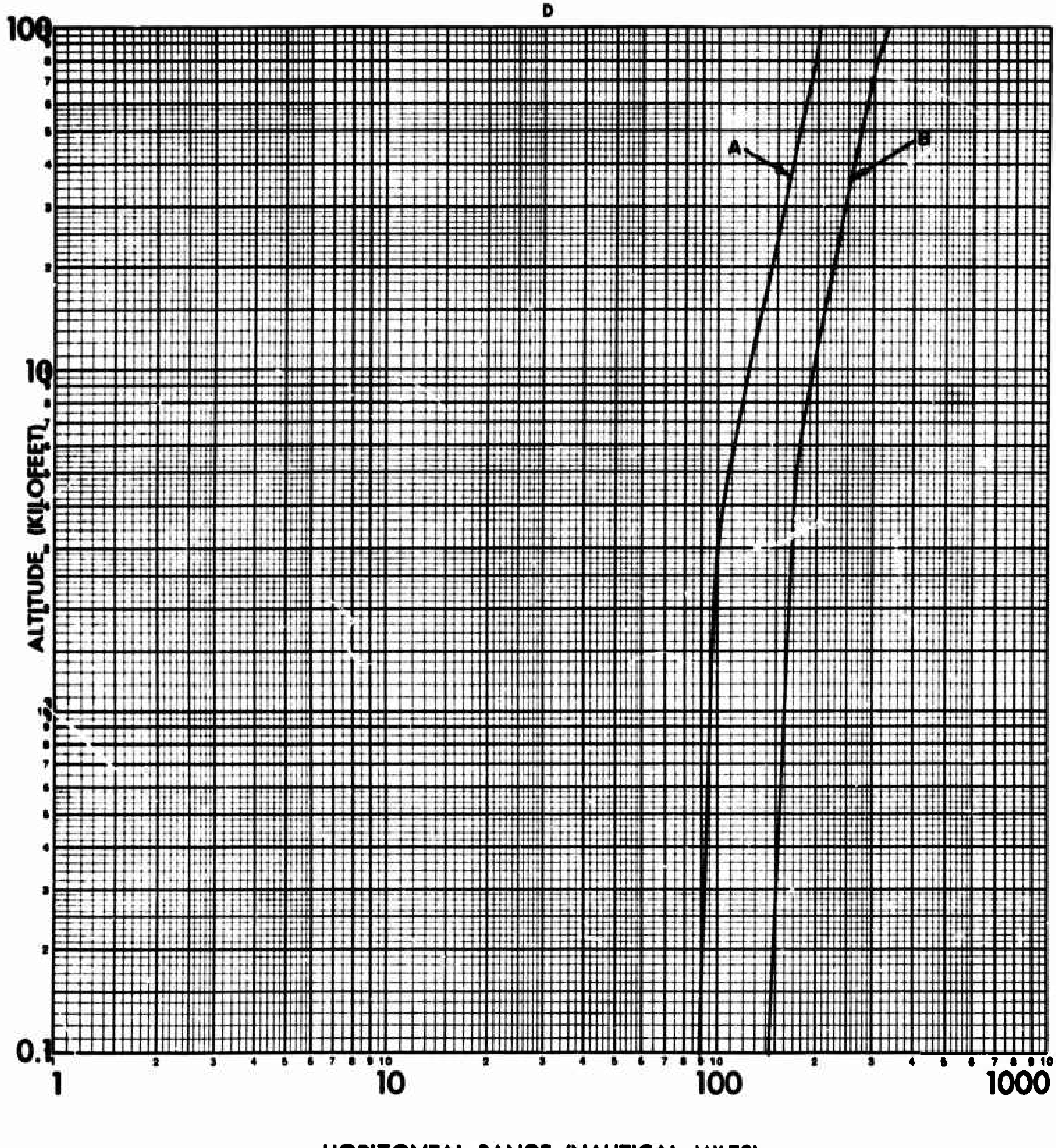


FIGURE 86

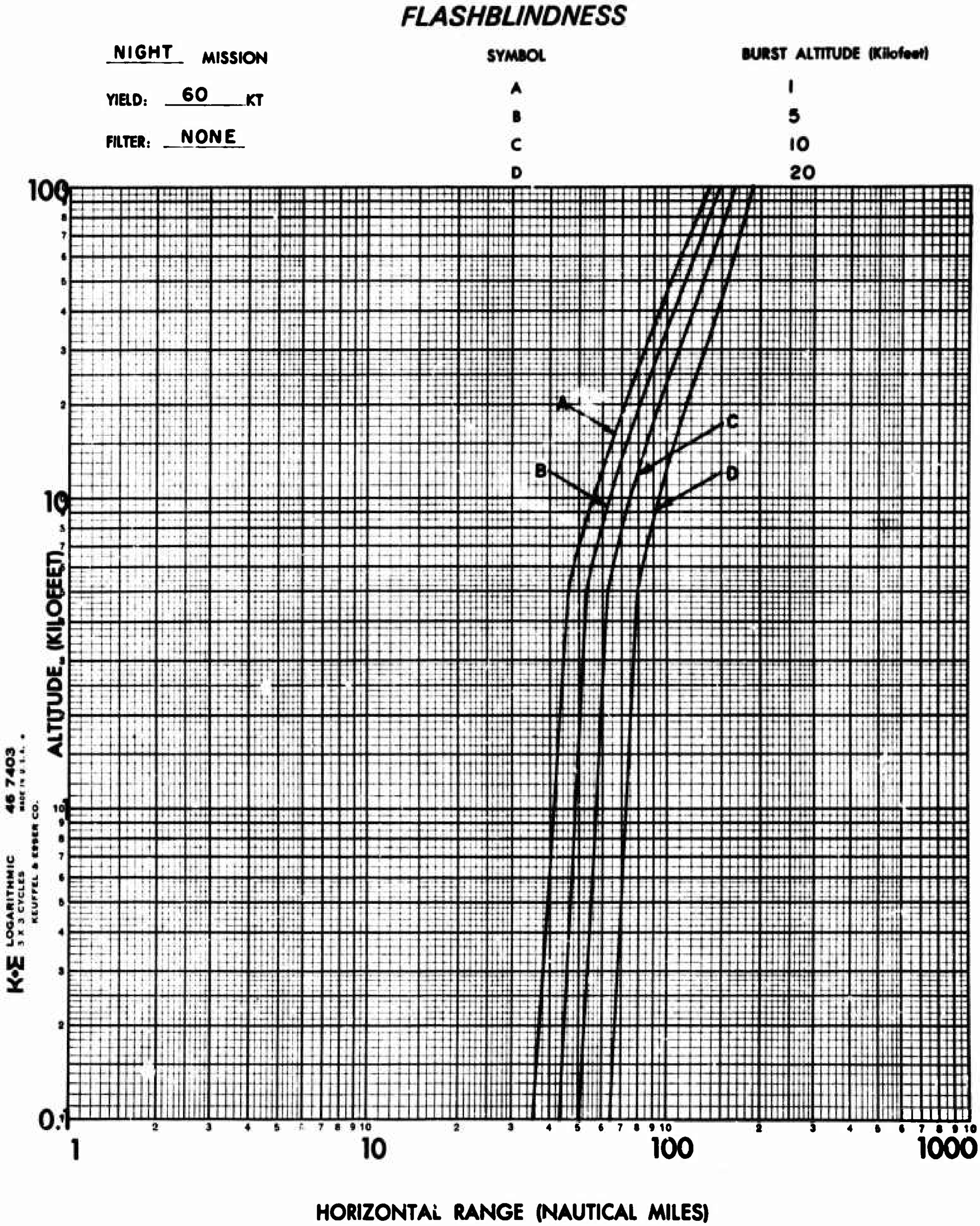

FLASHBLINDNESS
NIGHT MISSION
YIELD: 60 KT
FILTER: NONE
SYMBOL
BURST ALTITUDE (Kilofeet)
A 1
B 5
C 10
D 20
ALTITUDE, (KILOFEET)
HORIZONTAL RANGE (NAUTICAL MILES)
A
B
C
D
100
10
1
0.1
1
10
100
1000
K-E LOGARITHMIC 46 7403
3 X 3 CYCLES
KEUFFEL & ESSER CO.
MADE IN U.S.A.

FIGURE 87

FLASHBLINDNESS

NIGHT MISSION

YIELD: 60 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	

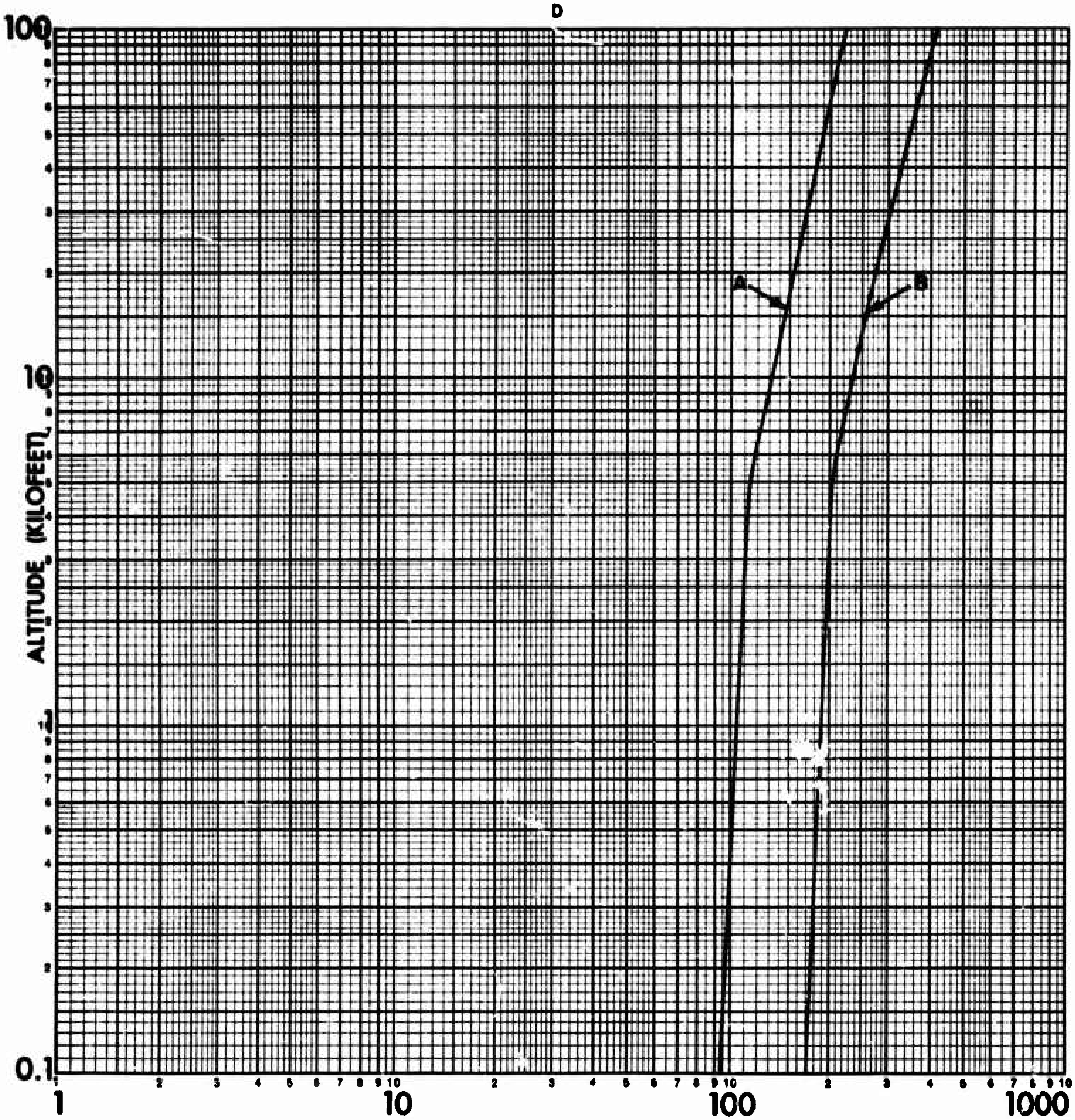


FIGURE 88

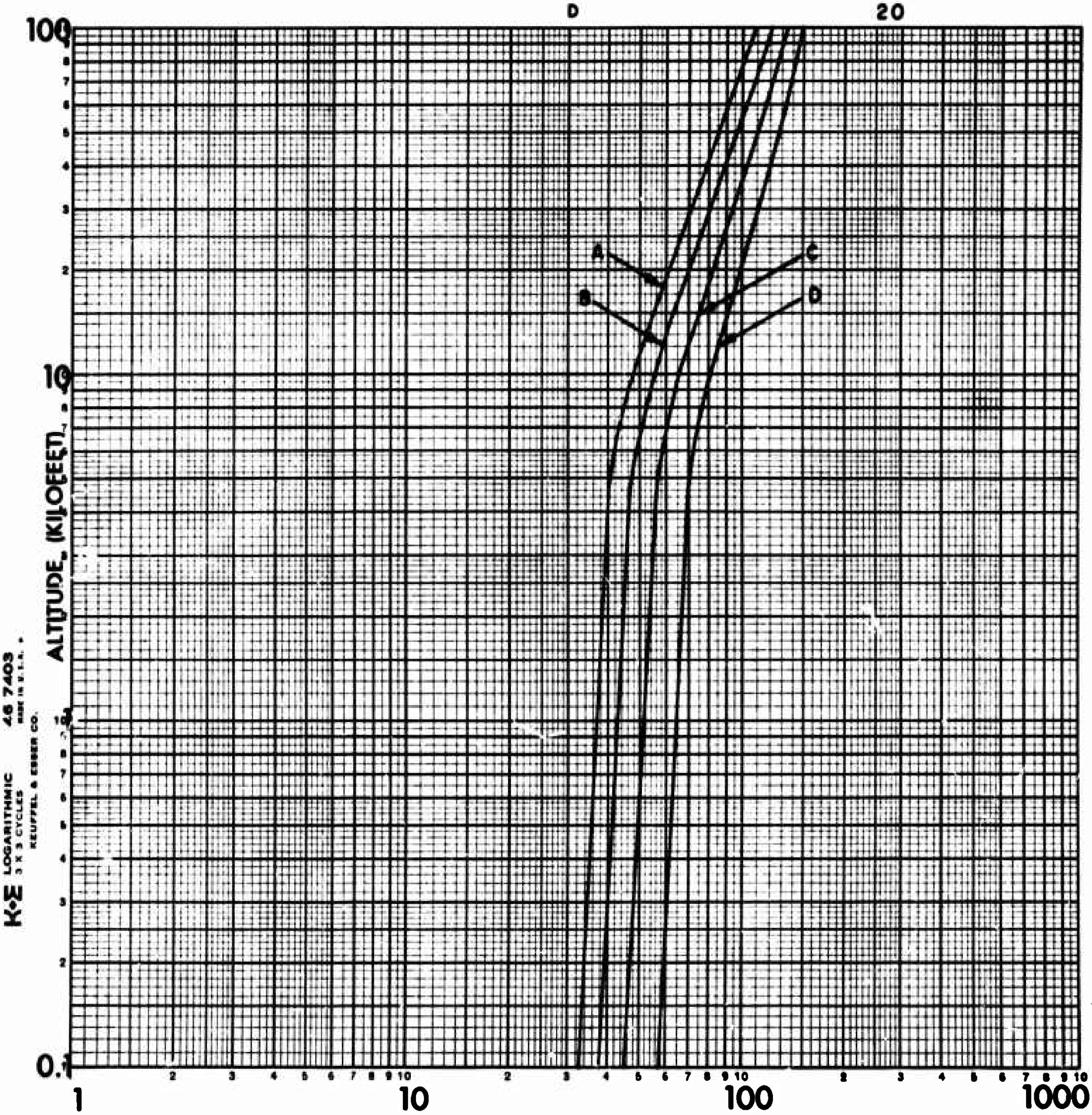
FLASHBLINDNESS

NIGHT MISSION

YIELD: 200 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1.5
B	5
C	10
D	20



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 89

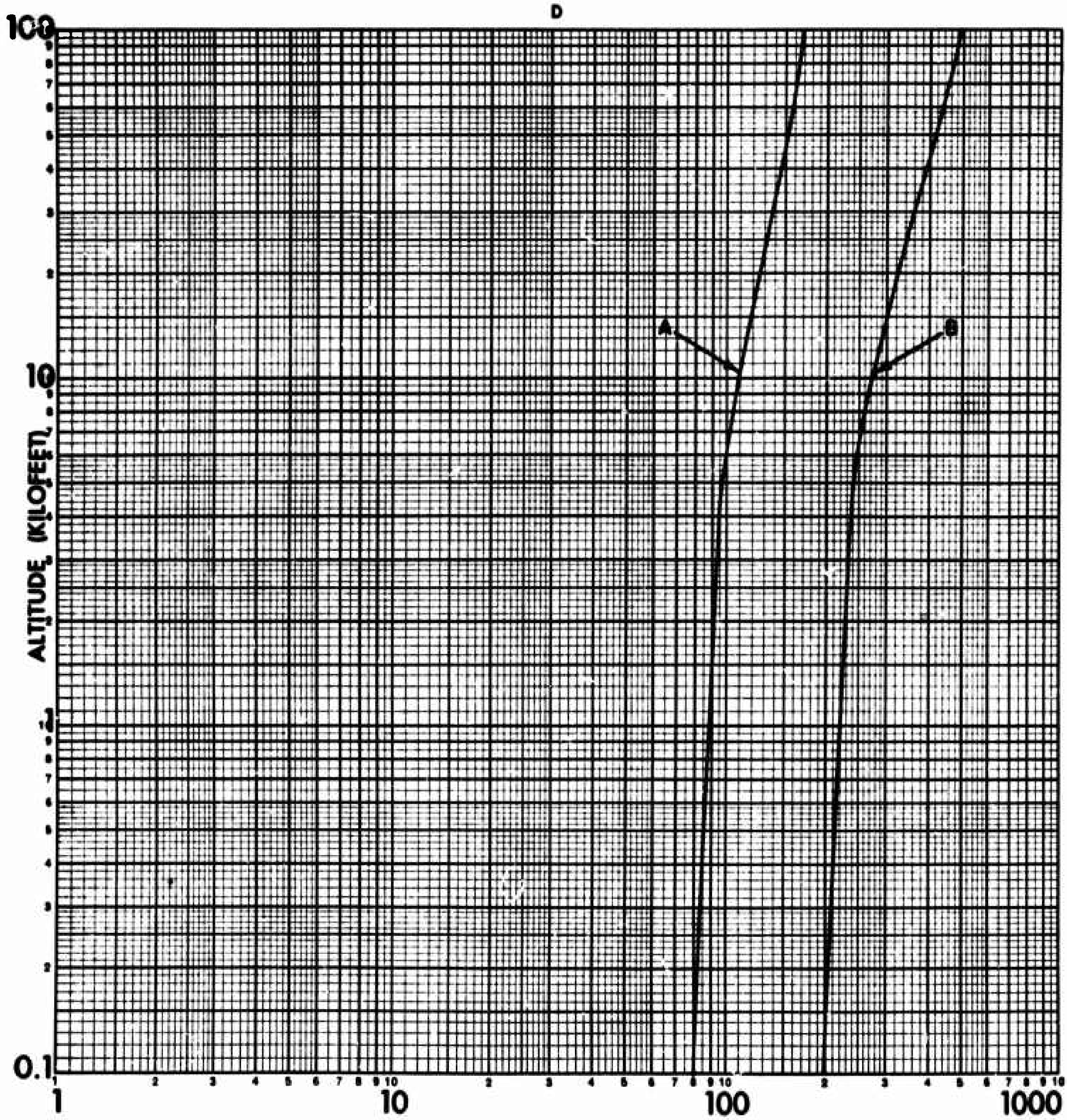
FLASHBLINDNESS

NIGHT MISSION

YIELD: 200 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 90

FLASHBLINDNESS

NIGHT MISSION

YIELD: 440 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1.5
B	5
C	10
D	20

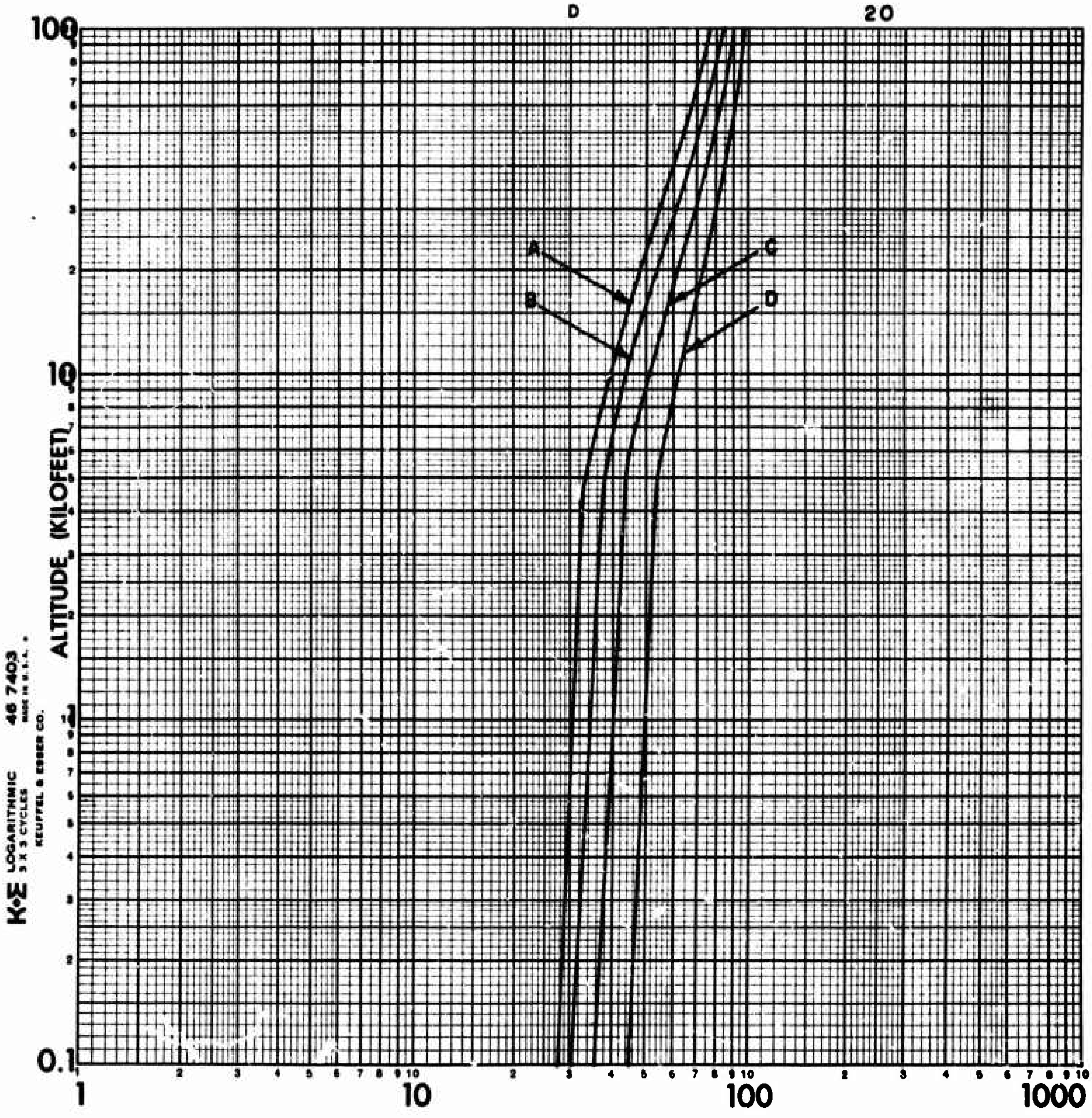


FIGURE 91

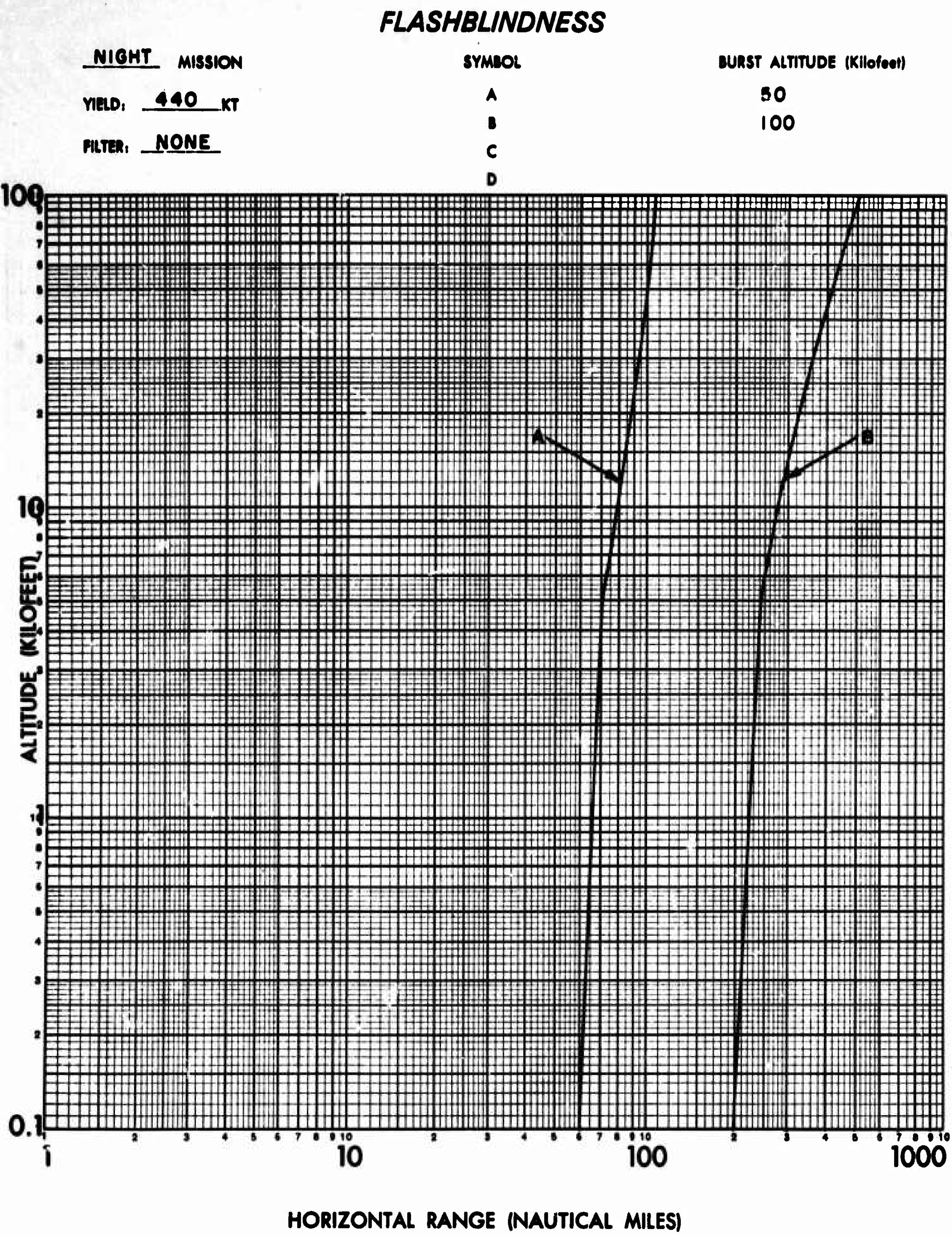

FLASHBLINDNESS
NIGHT MISSION
YIELD: 440 KT
FILTER: NONE
SYMBOL
A
B
C
D
BURST ALTITUDE (Kilofeet)
50
100
ALTITUDE (KILOFEET)
HORIZONTAL RANGE (NAUTICAL MILES)
100
10
1
0.1
1
10
100
1000
A
B

FIGURE 92

FLASHBLINDNESS

NIGHT MISSION

YIELD: 1000 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	3
B	10
C	25
D	50

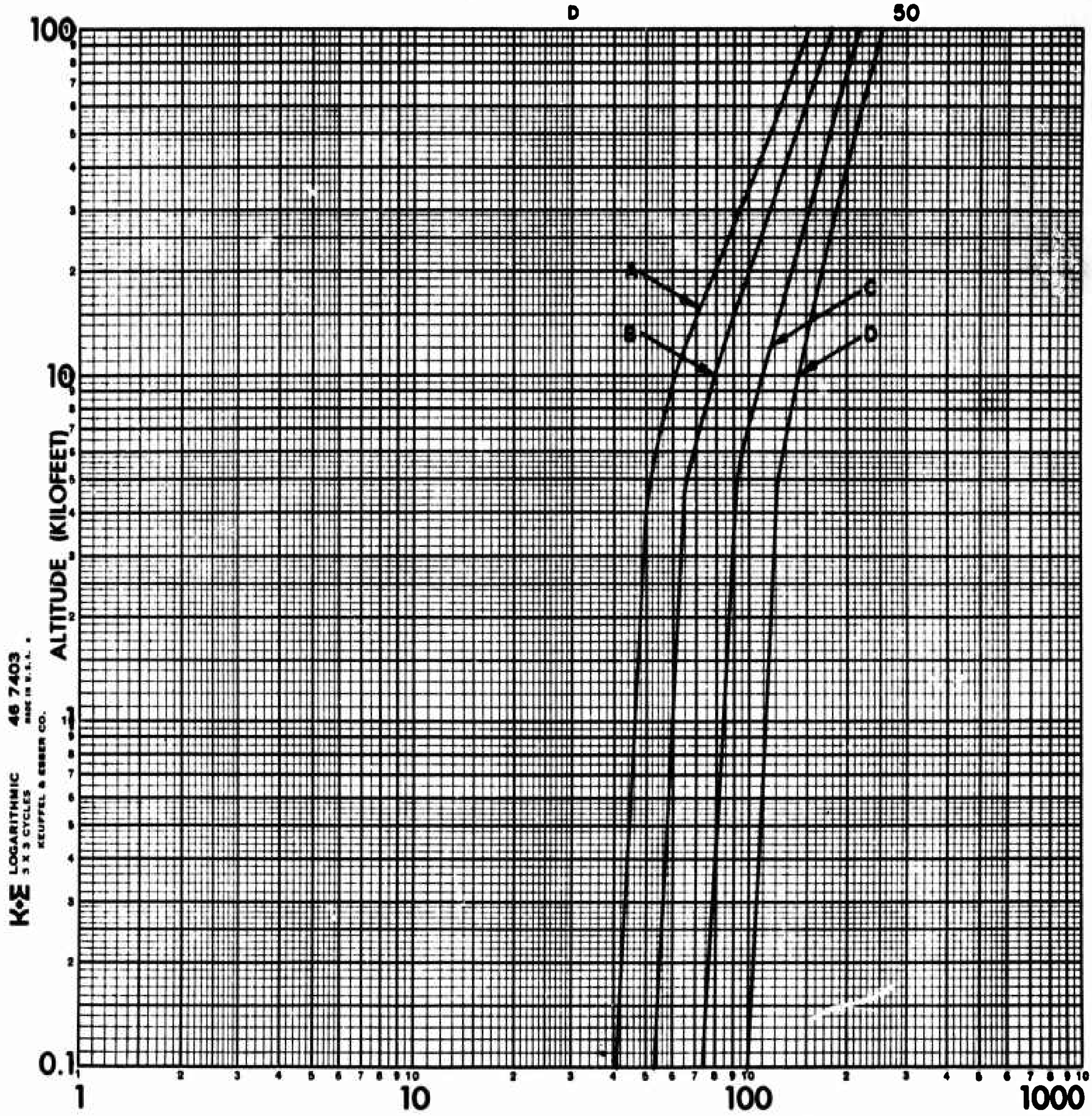


FIGURE 93

FLASHBLINDNESS

NIGHT MISSION

YIELD: 3800 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	4
B	10
C	25
D	50

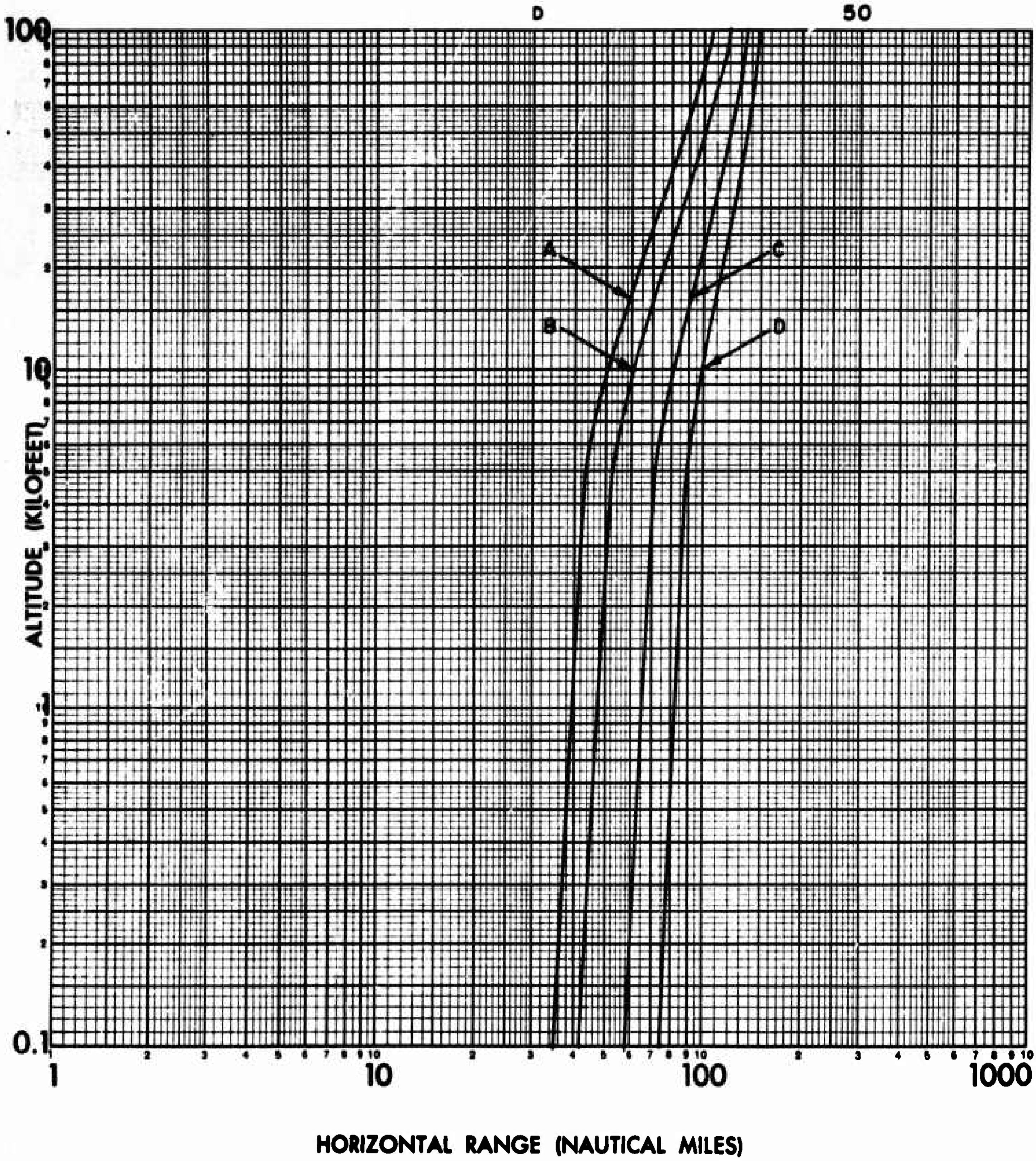


FIGURE 94

FLASHBLINDNESS

NIGHT MISSION

YIELD: 9000 KT

FILTER: NONE

SYMBOL	BURST ALTITUDE (Kilofeet)
A	5
B	10
C	25
D	50

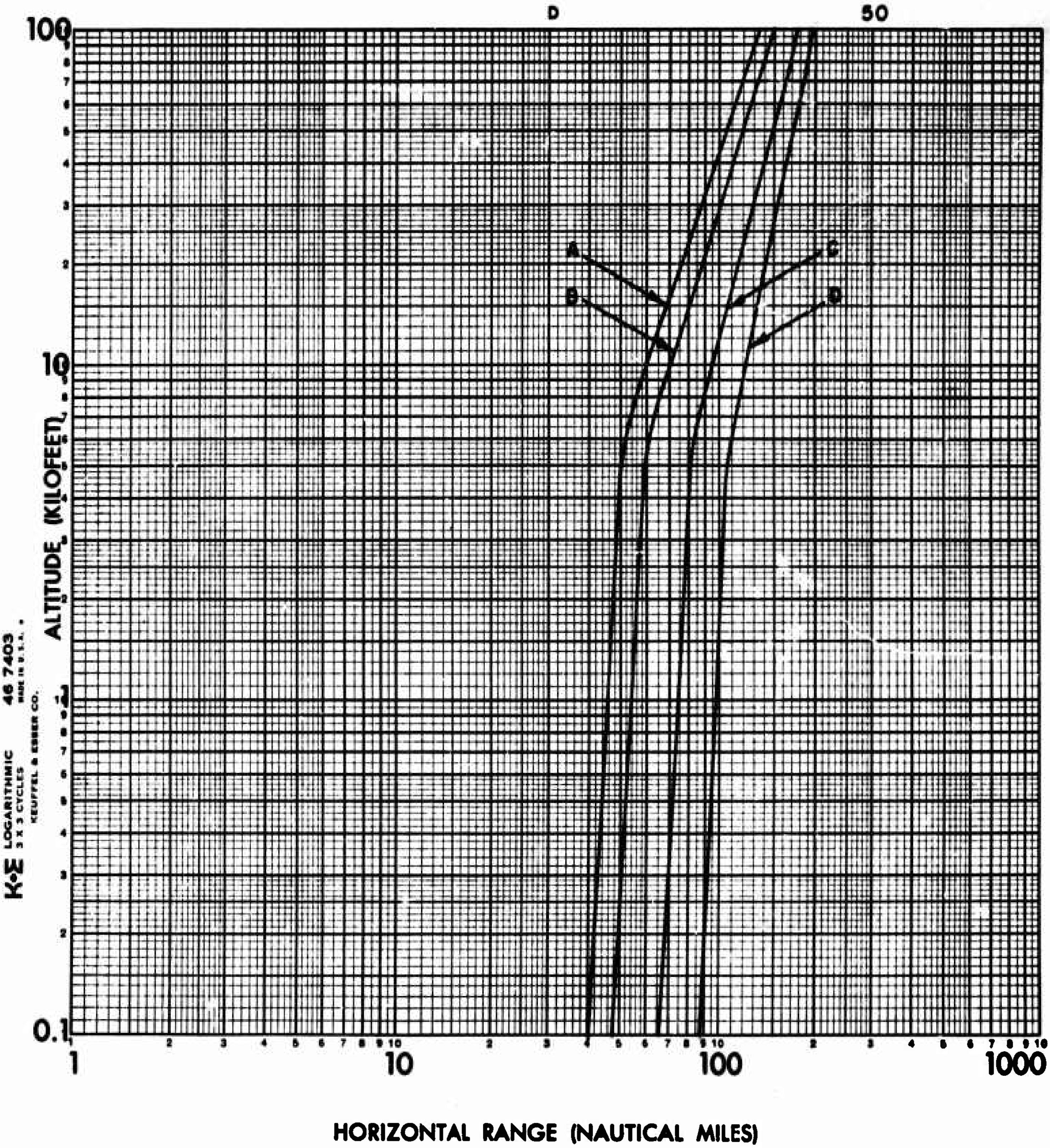


FIGURE 95

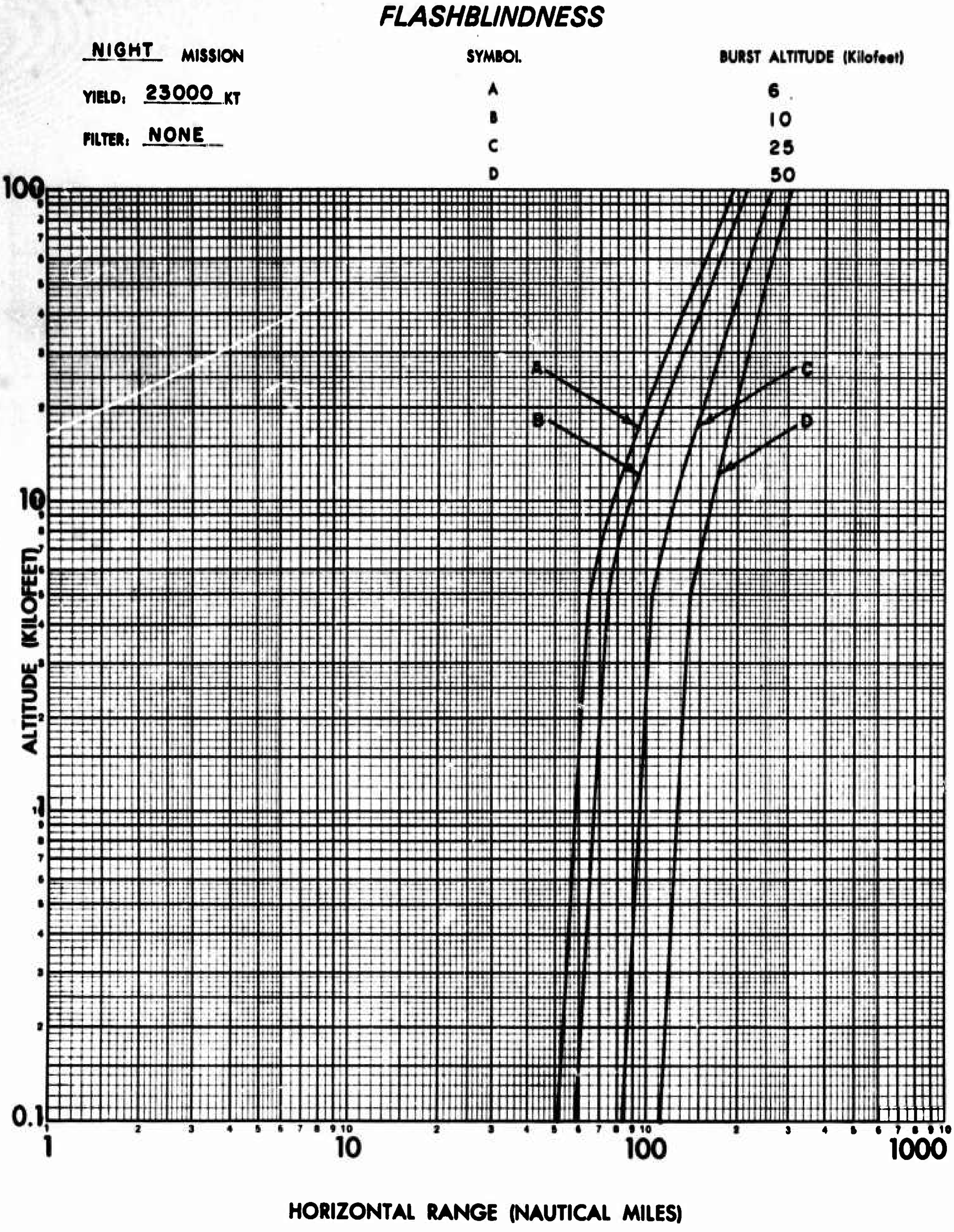

FLASHBLINDNESS
NIGHT MISSION
YIELD: 23000 KT
FILTER: NONE
SYMBOL
BURST ALTITUDE (Kilofeet)
A 6
B 10
C 25
D 50
ALTITUDE (KILOFEET)
100
10
1
0.1
1
10
100
1000
A
B
C
D
HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 96

FLASHBLINDNESS SAFE SEPARATION ENVELOPES

DAY MISSION WITH 2% FILTER

FLASHBLINDNESS

DAY MISSION

YIELD: 0.02 KT

FILTER: 2 %

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	10
C	25
D	50

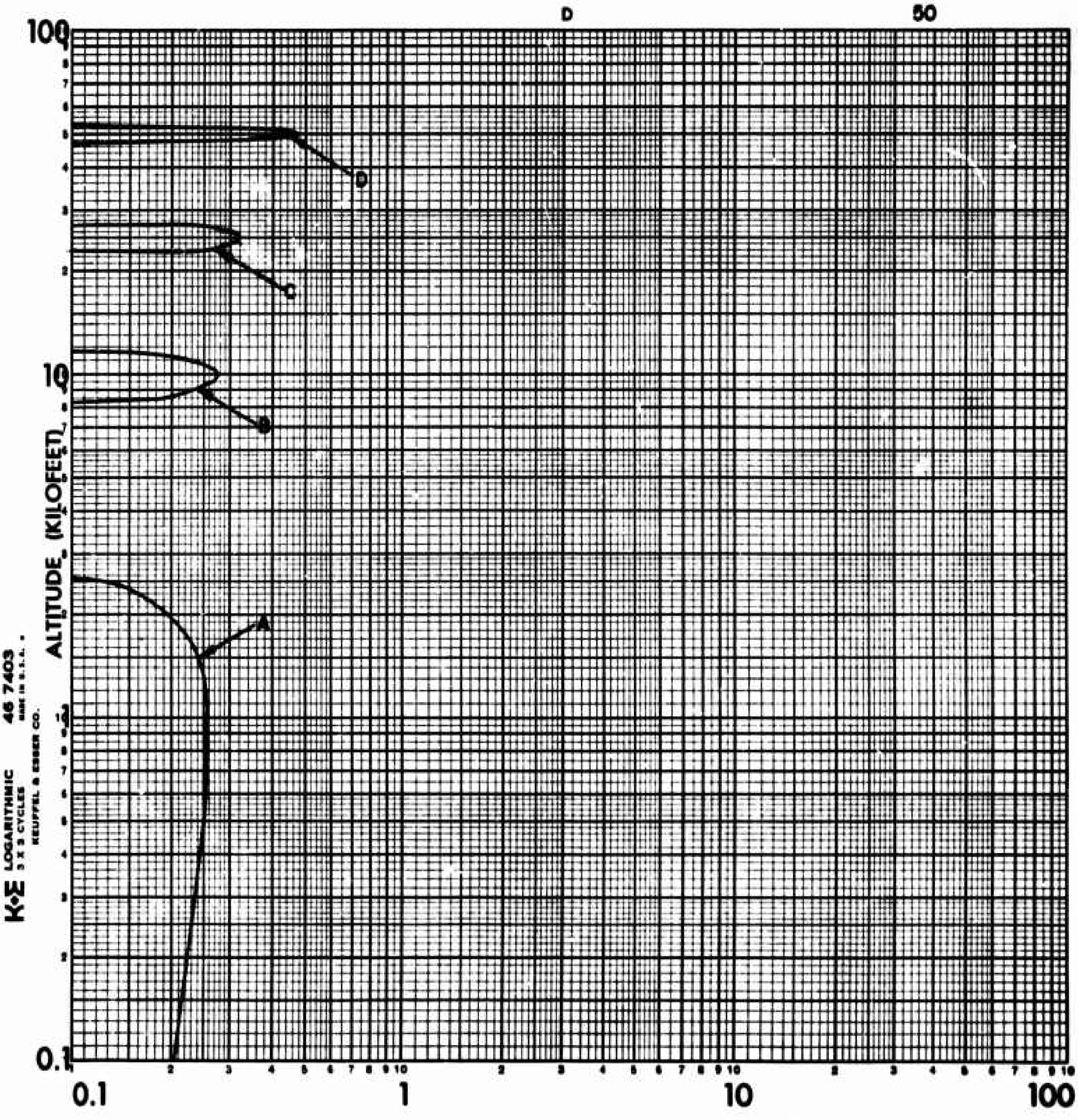


FIGURE 97

FLASHBLINDNESS

DAY MISSION

YIELD: 0.02 KT

FILTER: 2%

SYMBOL	BURST ALTITUDE (Kilofeet)
A	75
B	100
C	
D	

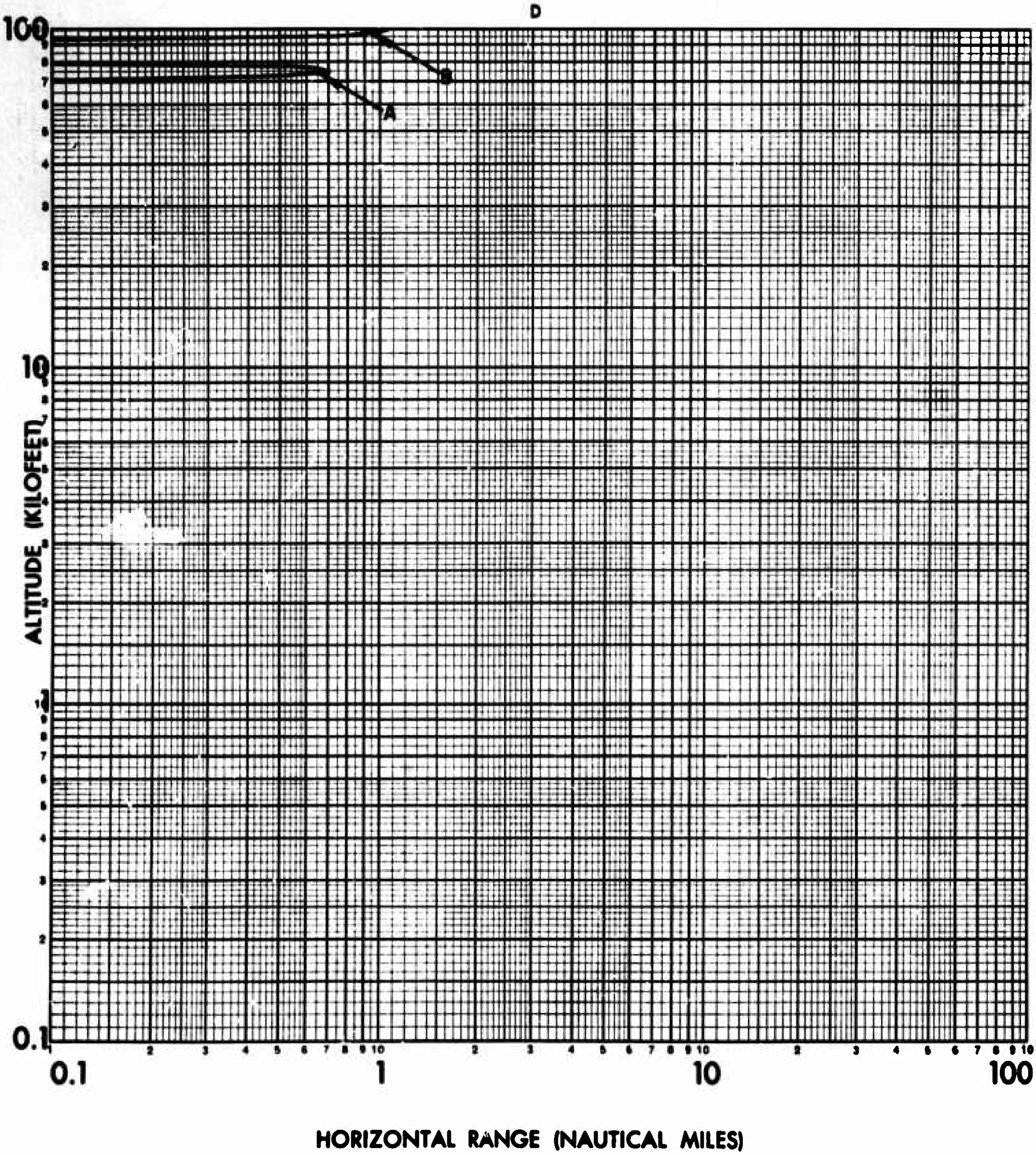


FIGURE 98

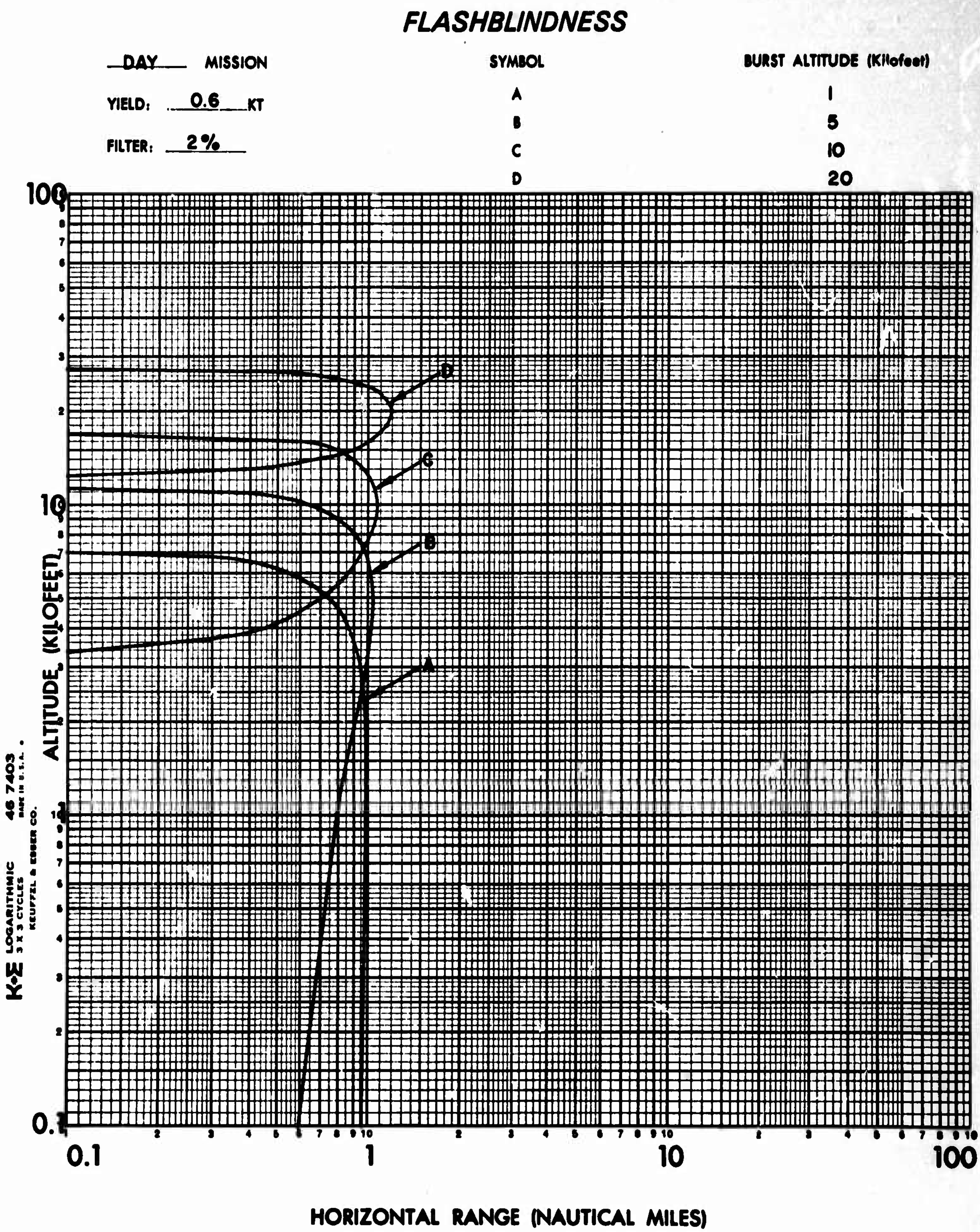

FLASHBLINDNESS
DAY MISSION
YIELD: 0.6 KT
FILTER: 2%
SYMBOL
BURST ALTITUDE (Kilofeet)
A 1
B 5
C 10
D 20
ALTITUDE (KILOFEET)
HORIZONTAL RANGE (NAUTICAL MILES)
0.1
1
10
100
K+E LOGARITHMIC 3 X 3 CYCLES
46 7403
KEUFFEL & ESSER CO.

FIGURE 99

FLASHBLINDNESS

DAY MISSION

YIELD: 0.6 KT

FILTER: 2%

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	

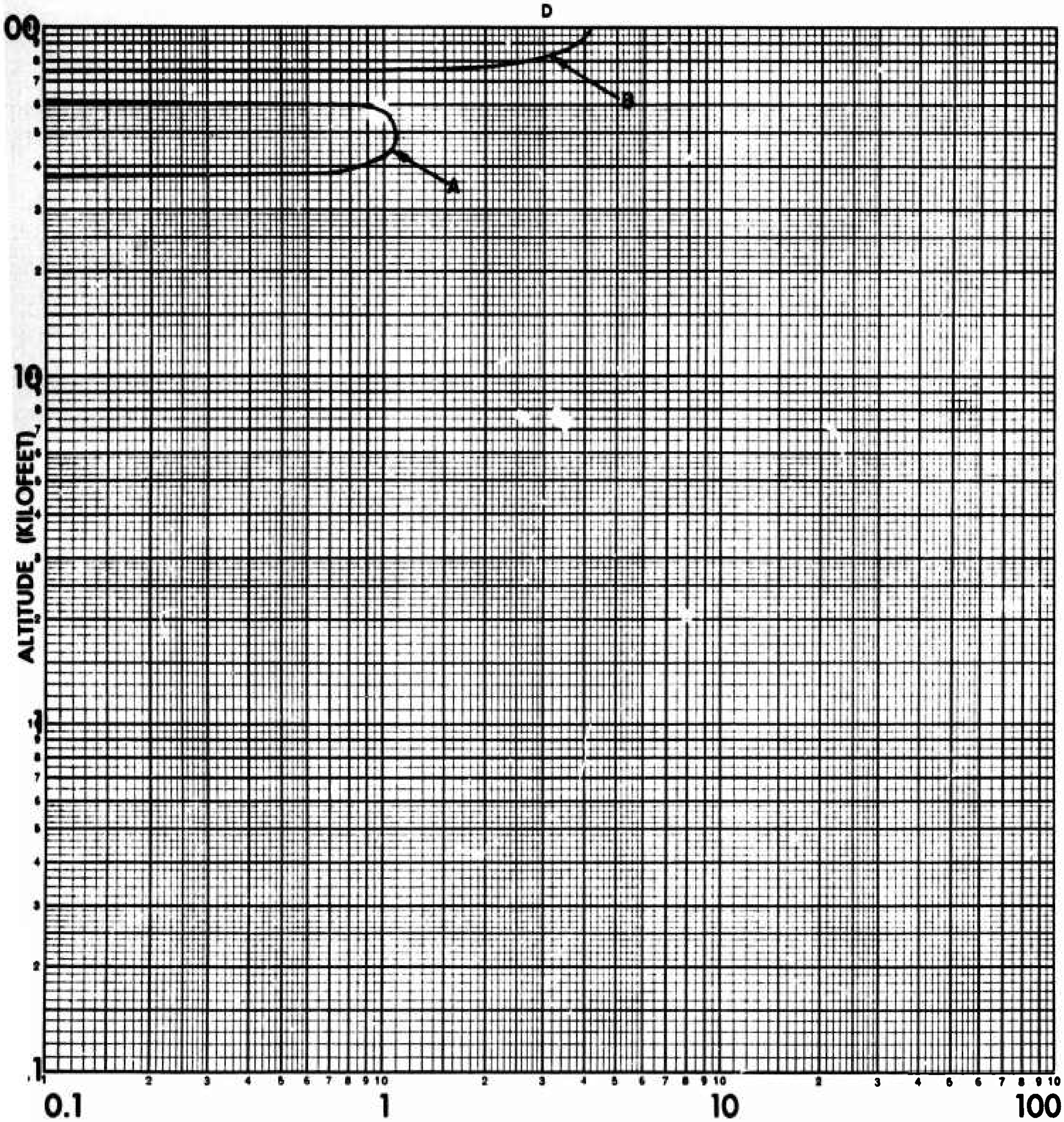


FIGURE 100

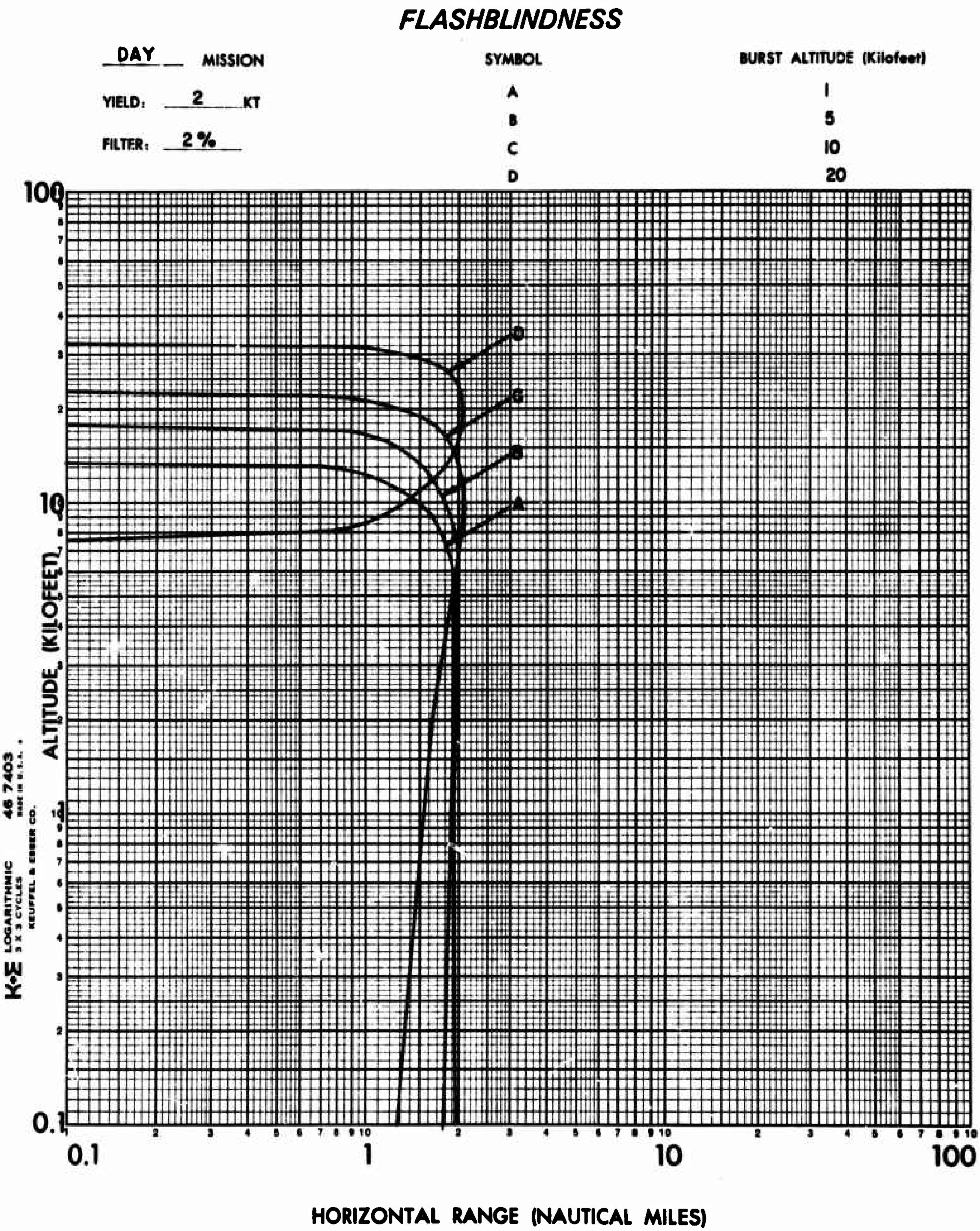

FLASHBLINDNESS
DAY MISSION
YIELD: 2 KT
FILTER: 2 %
SYMBOL
BURST ALTITUDE (Kilofeet)
A 1
B 5
C 10
D 20
ALTITUDE (KILOFEET)
HORIZONTAL RANGE (NAUTICAL MILES)
0.1
1
10
100
K+E LOGARITHMIC 46 7403
3 X 3 CYCLES
KEUFFEL & ESSER CO.

FIGURE 101

FLASHBLINDNESS

DAY MISSION

YIELD: 2 KT

FILTER: 2%

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	

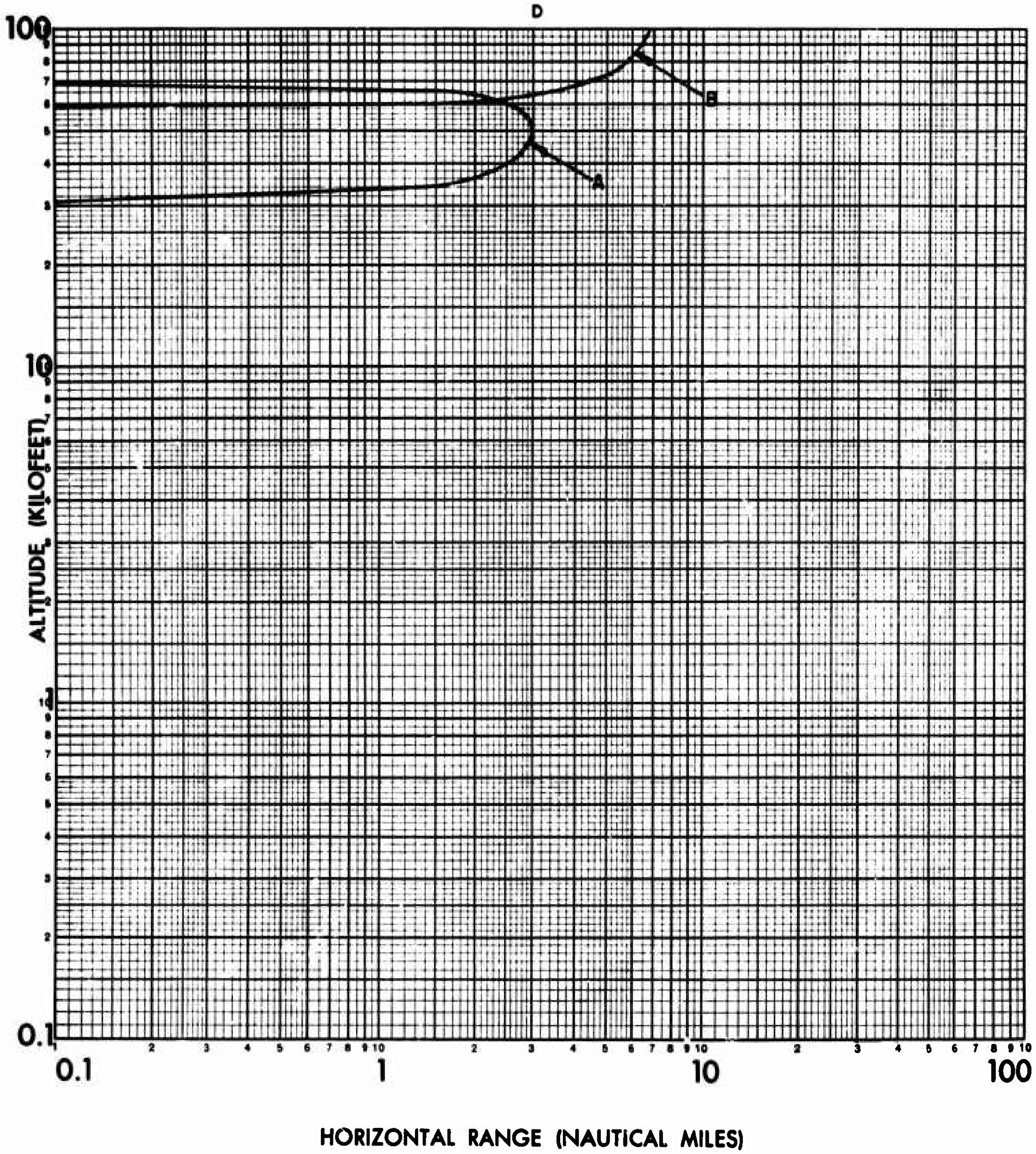


FIGURE 102

FLASHBLINDNESS

DAY MISSION		SYMBOL	BURST ALTITUDE (Kilofeet)
YIELD: 10 KT		A	1
		B	5
FILTER: 2%		C	10
		D	20

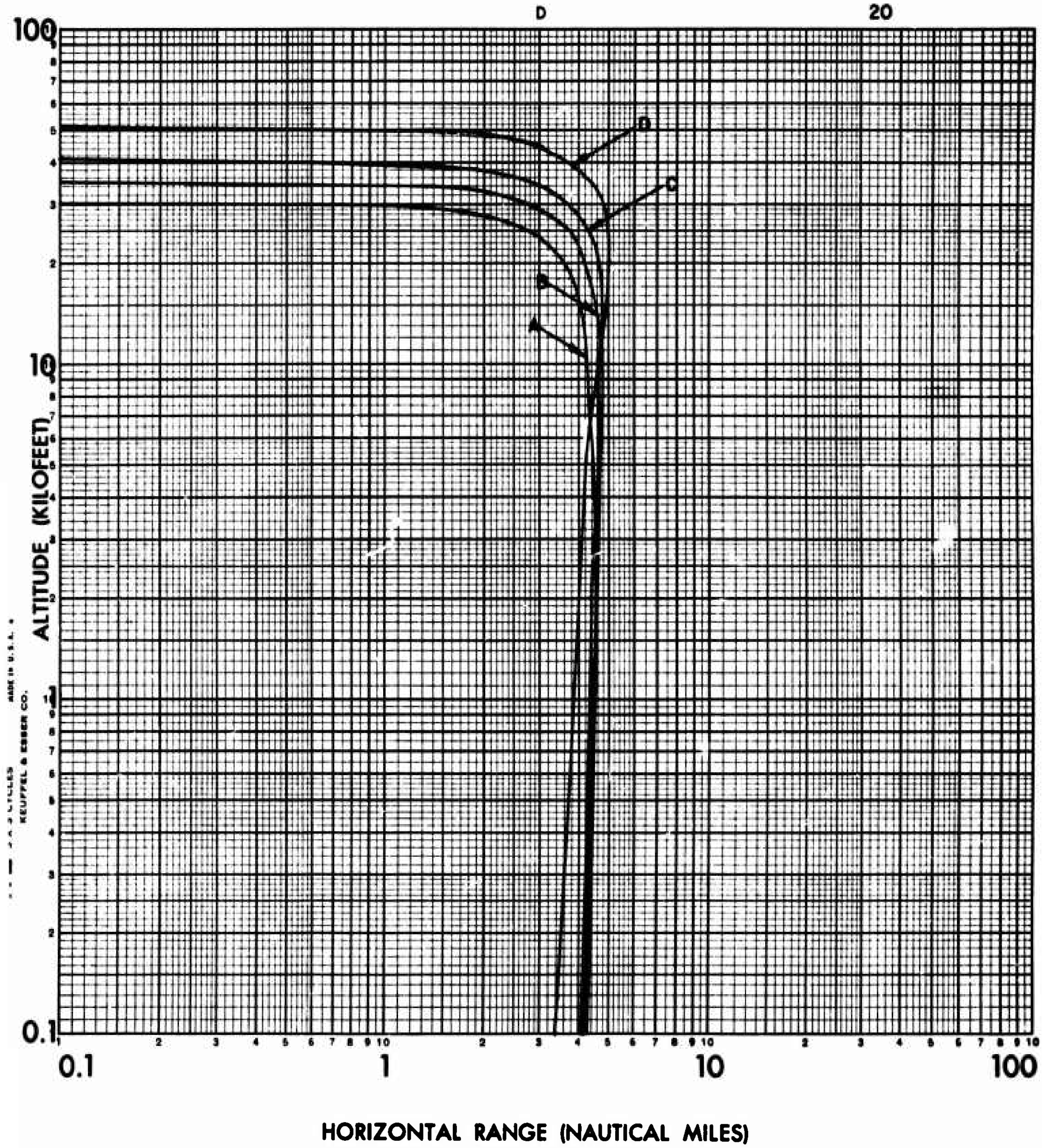


FIGURE 103

FLASHBLINDNESS

DAY MISSION

YIELD: 10 KT

FILTER: 2 %

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	

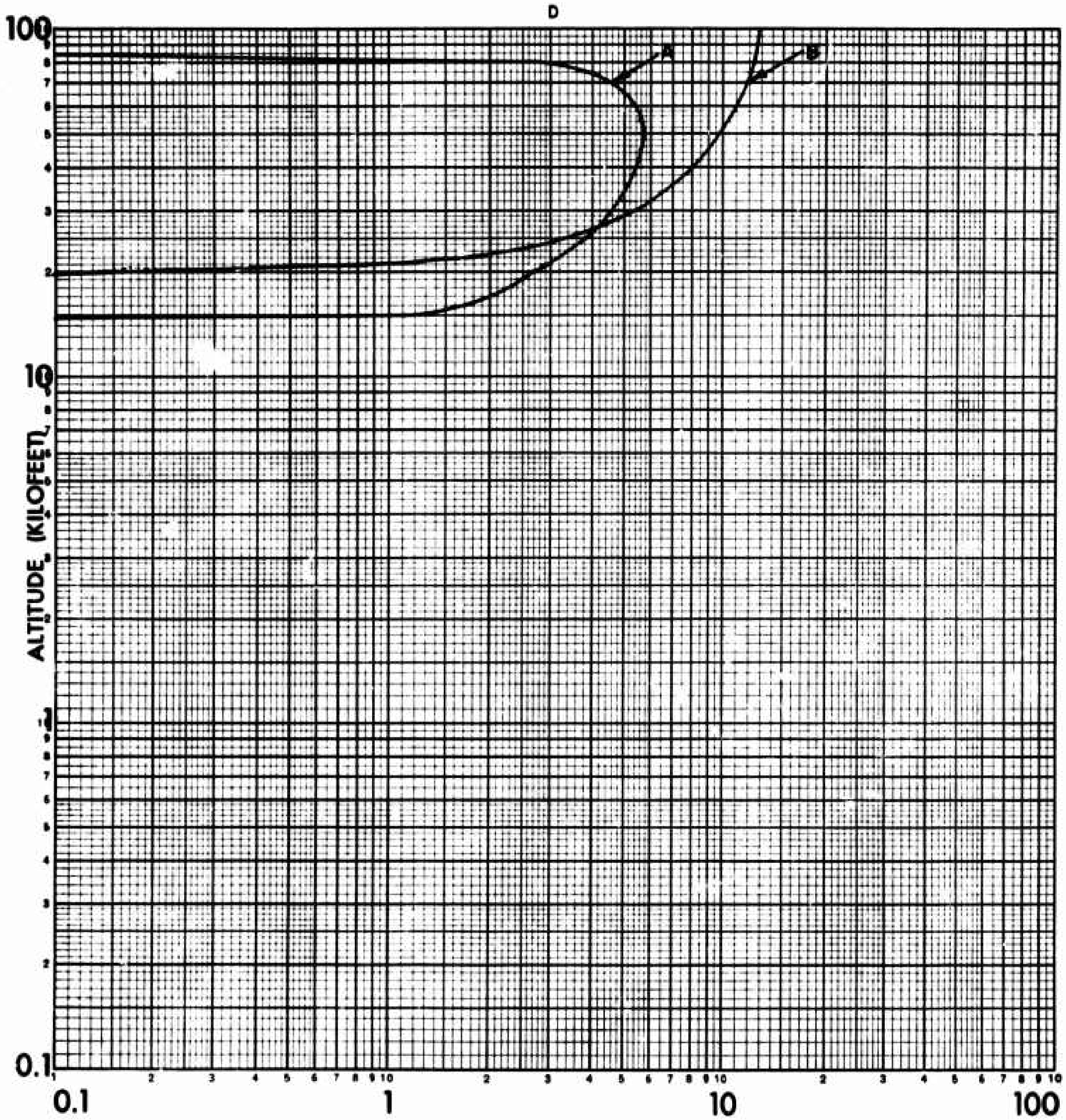


FIGURE 104

FLASHBLINDNESS

DAY MISSION

YIELD: 30 KT

FILTER: 2 %

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	5
C	10
D	20

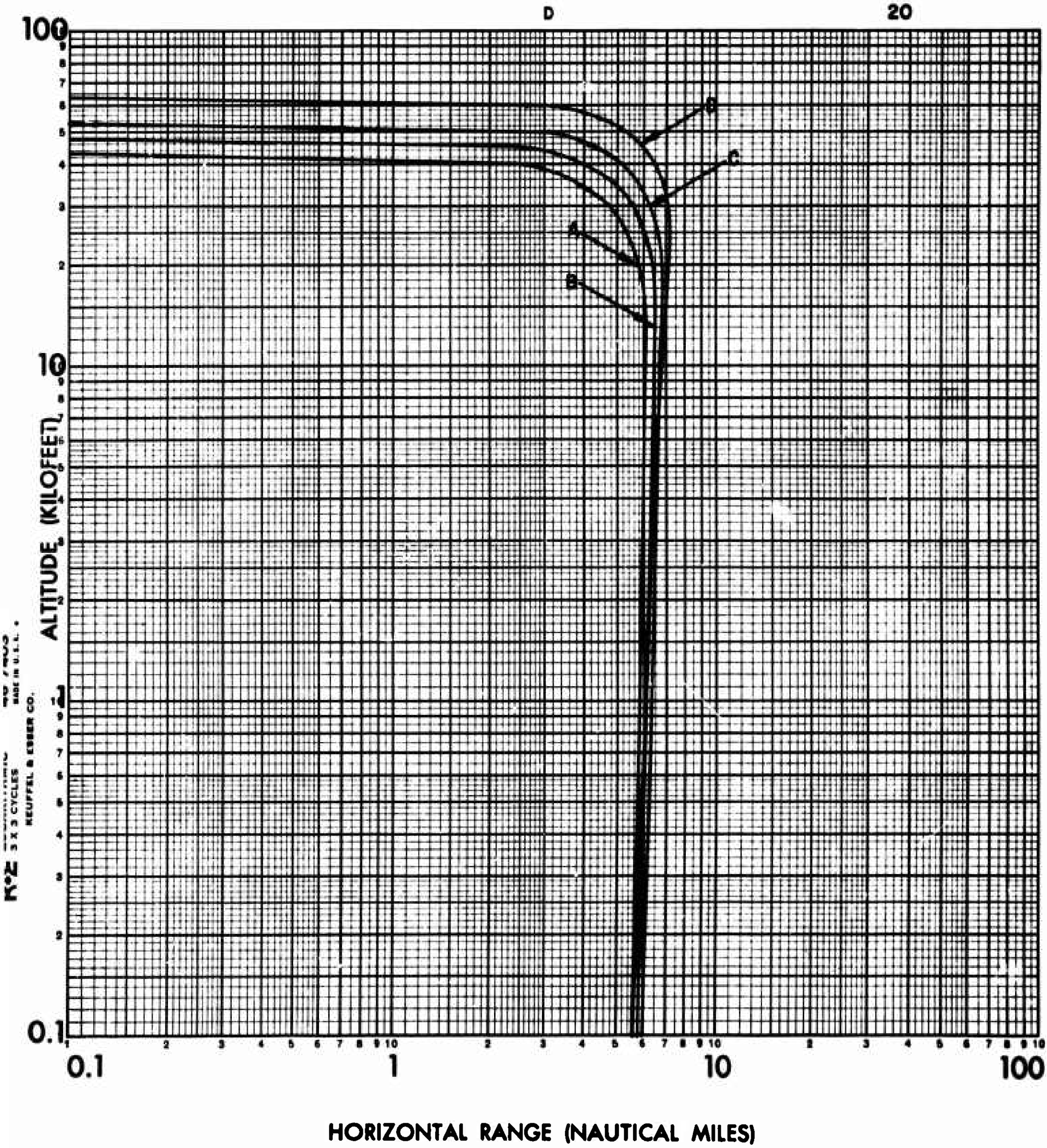
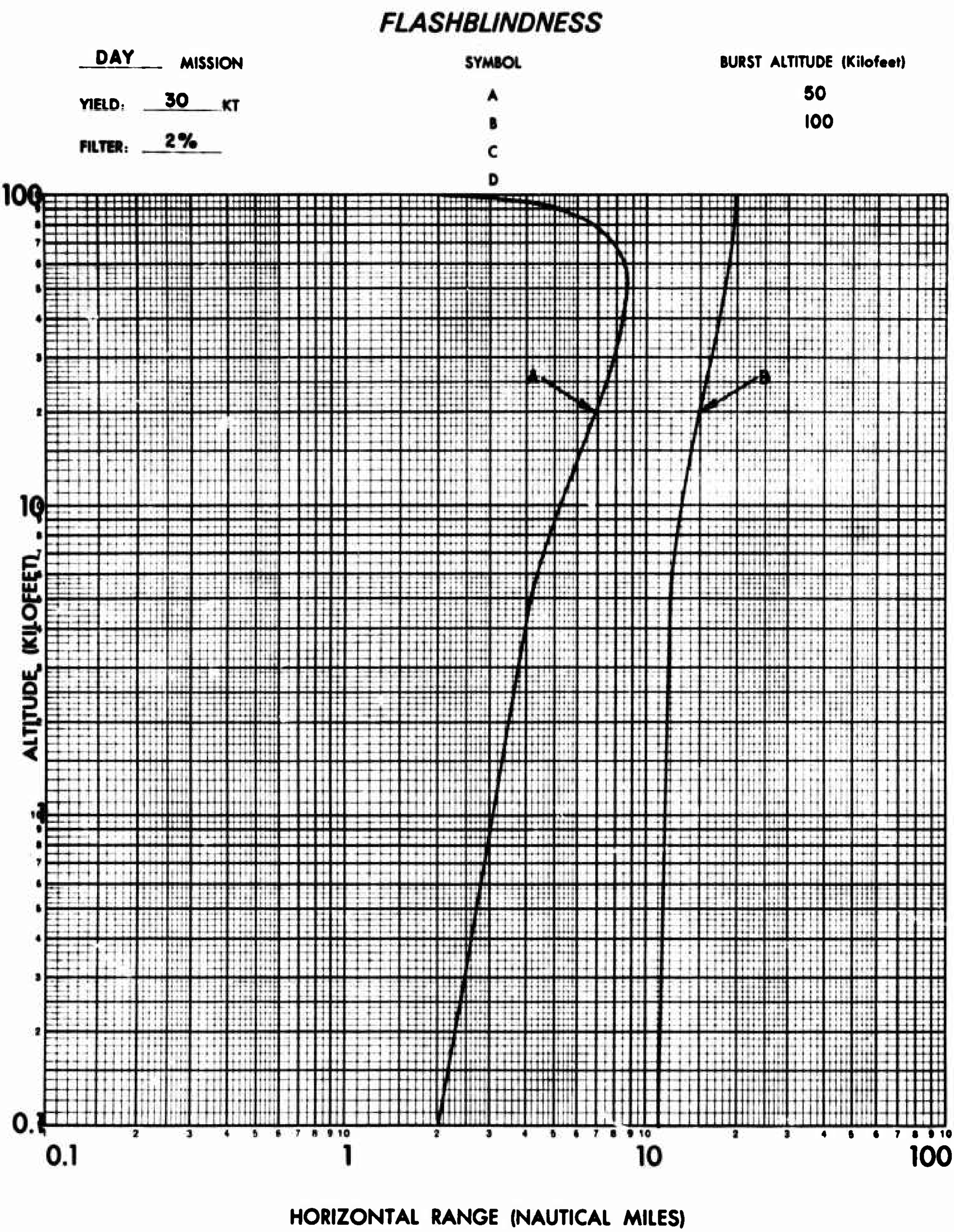


FIGURE 105



FLASHBLINDNESS
DAY MISSION
YIELD: 30 KT
FILTER: 2%
SYMBOL
A
B
C
D
BURST ALTITUDE (Kilofeet)
50
100
A
B
ALTITUDE (KILOFEET)
100
10
0.1
HORIZONTAL RANGE (NAUTICAL MILES)
0.1
1
10
100

FIGURE 106

FLASHBLINDNESS

DAY MISSION

YIELD: 60 KT

FILTER: 2%

SYMBOL	BURST ALTITUDE (Kilofeet)
A	1
B	5
C	10
D	20

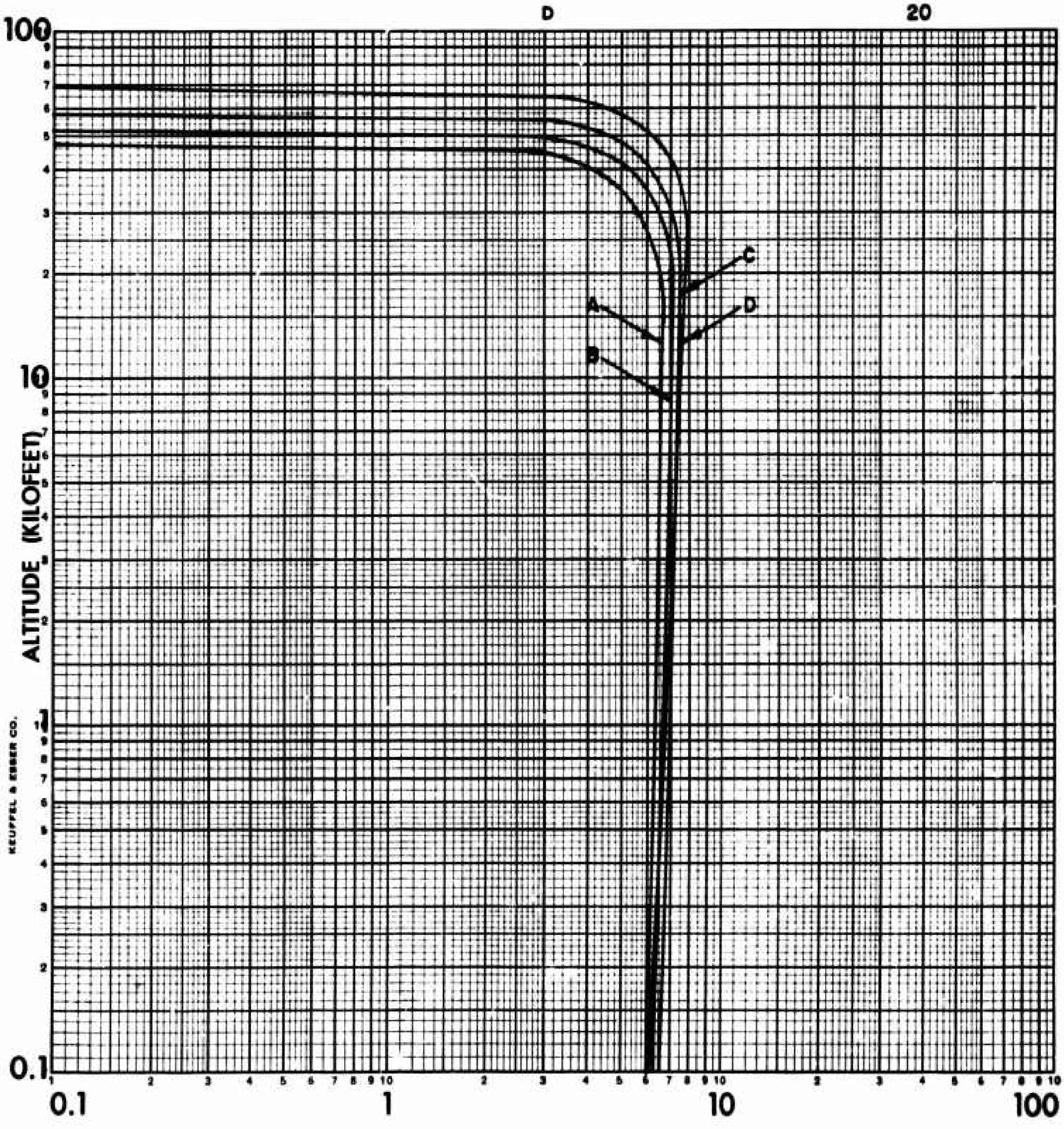


FIGURE 107

FLASHBLINDNESS

DAY MISSION	SYMBOL	BURST ALTITUDE (Kilofeet)
YIELD: 60 KT	A	50
FILTER: 2 %	B	100
	C	
	D	

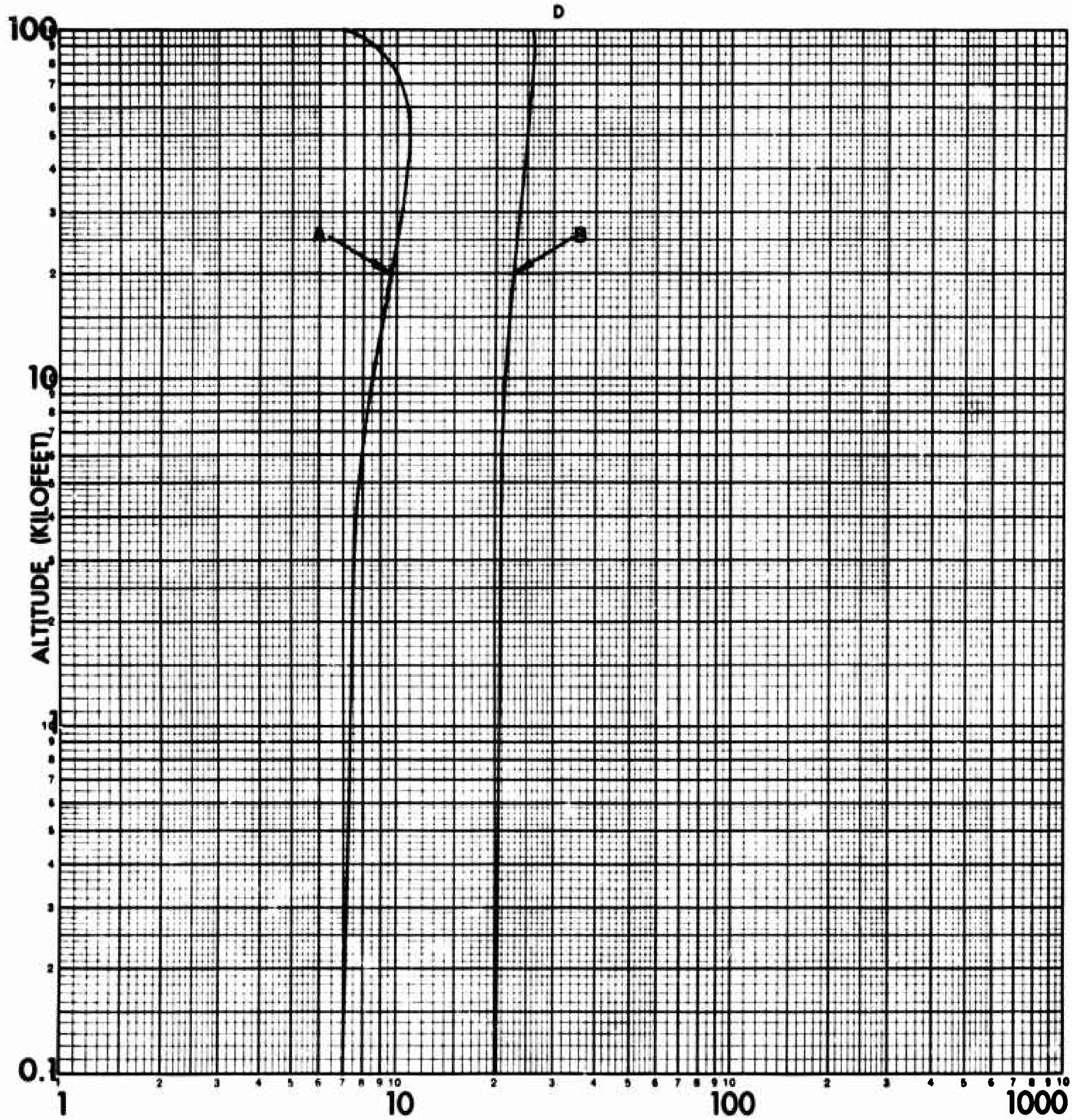
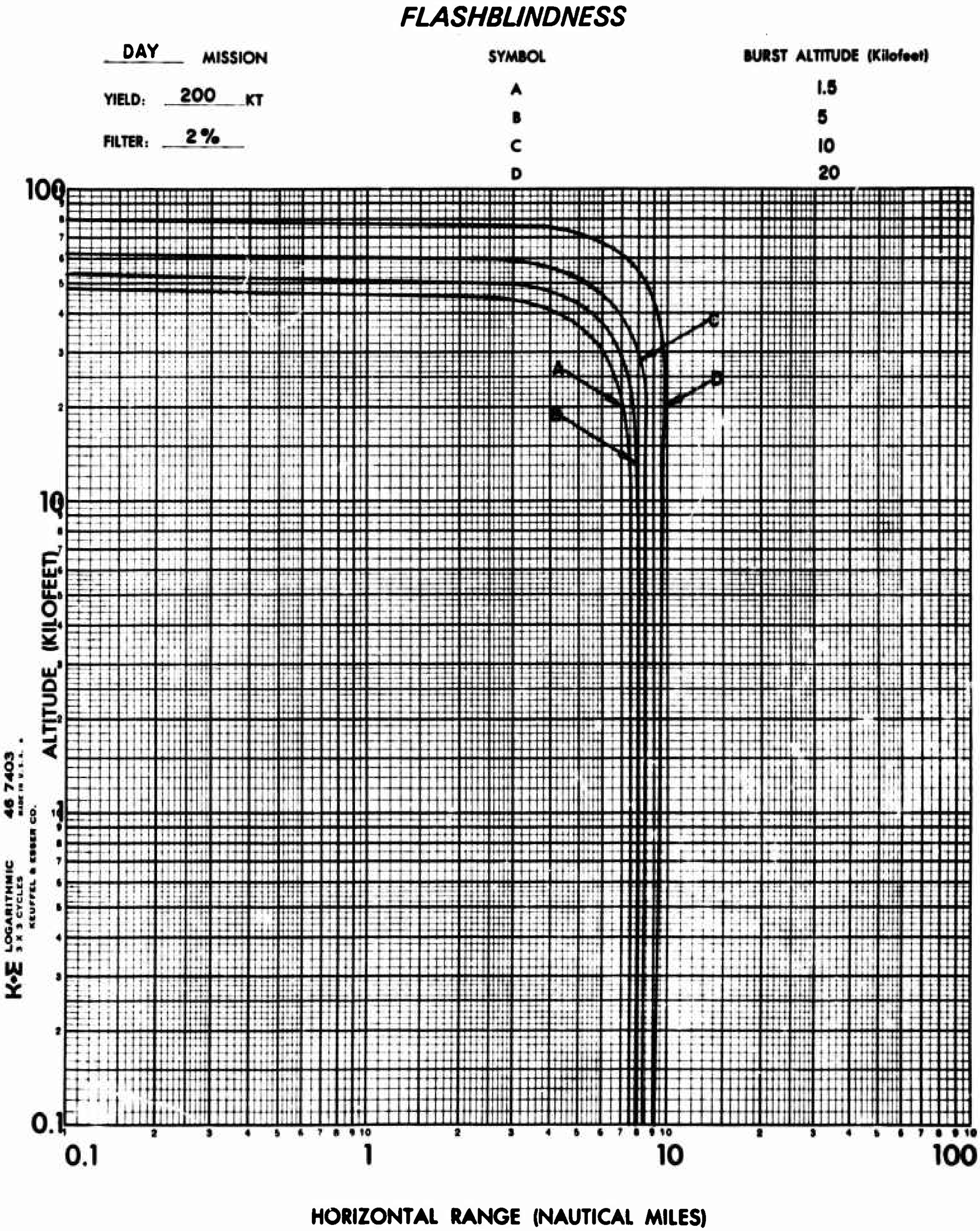


FIGURE 108



FLASHBLINDNESS
DAY MISSION
YIELD: 200 KT
FILTER: 2 %
SYMBOL
BURST ALTITUDE (Kilofeet)
A
1.5
B
5
C
10
D
20
100
10
1
0.1
ALTITUDE (KILOFEET)
A
B
C
D
0.1
1
10
100
HORIZONTAL RANGE (NAUTICAL MILES)
K·E LOGARITHMIC 46 7403
KEUFFEL & ESSER CO.

FIGURE 109

FLASHBLINDNESS

DAY MISSION

YIELD: 200 KT

FILTER: 2%

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	

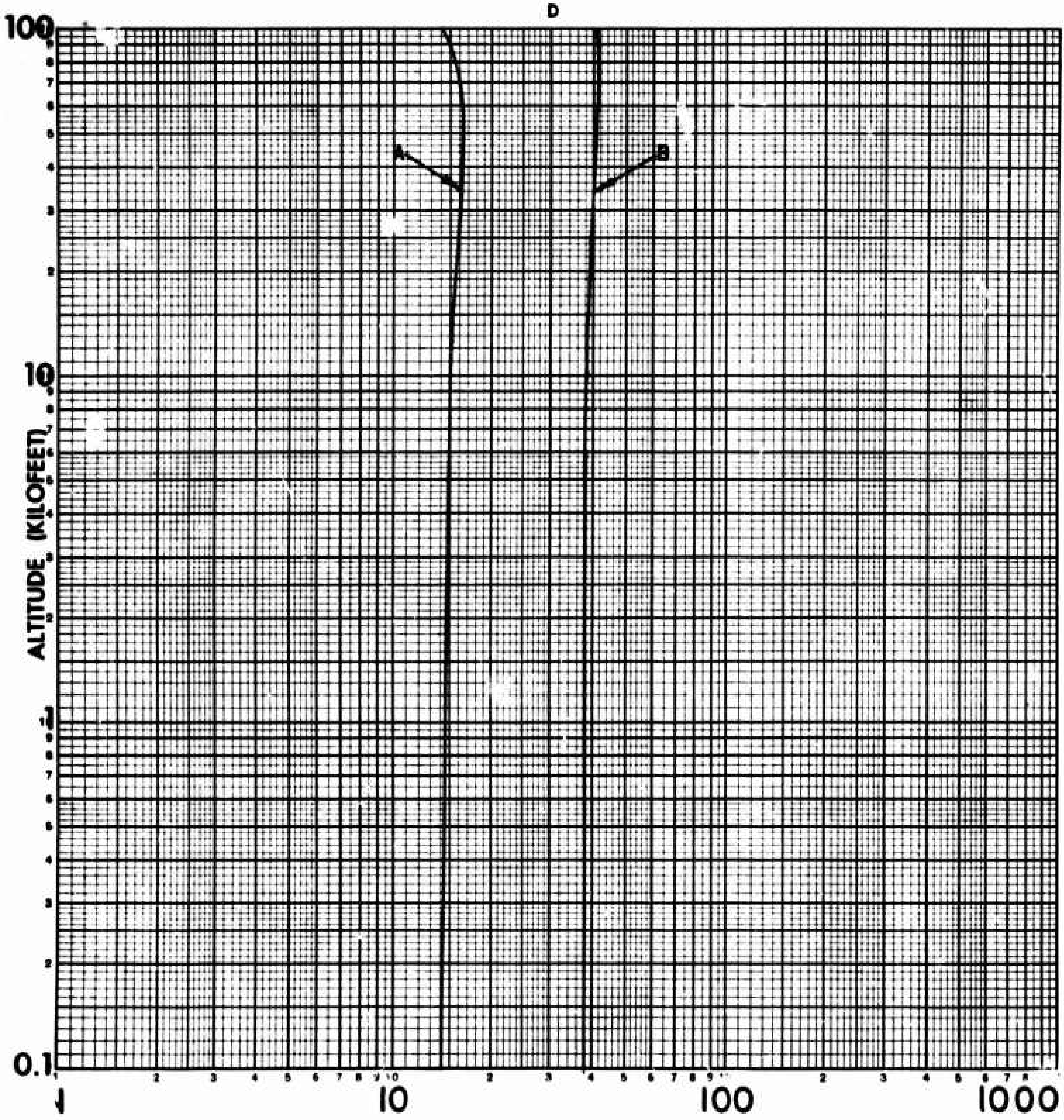


FIGURE 110

FLASHBLINDNESS

DAY MISSION	SYMBOL	BURST ALTITUDE (Kilofeet)
YIELD: 440 KT	A	1.5
FILTER: 2 %	B	5
	C	10
	D	20

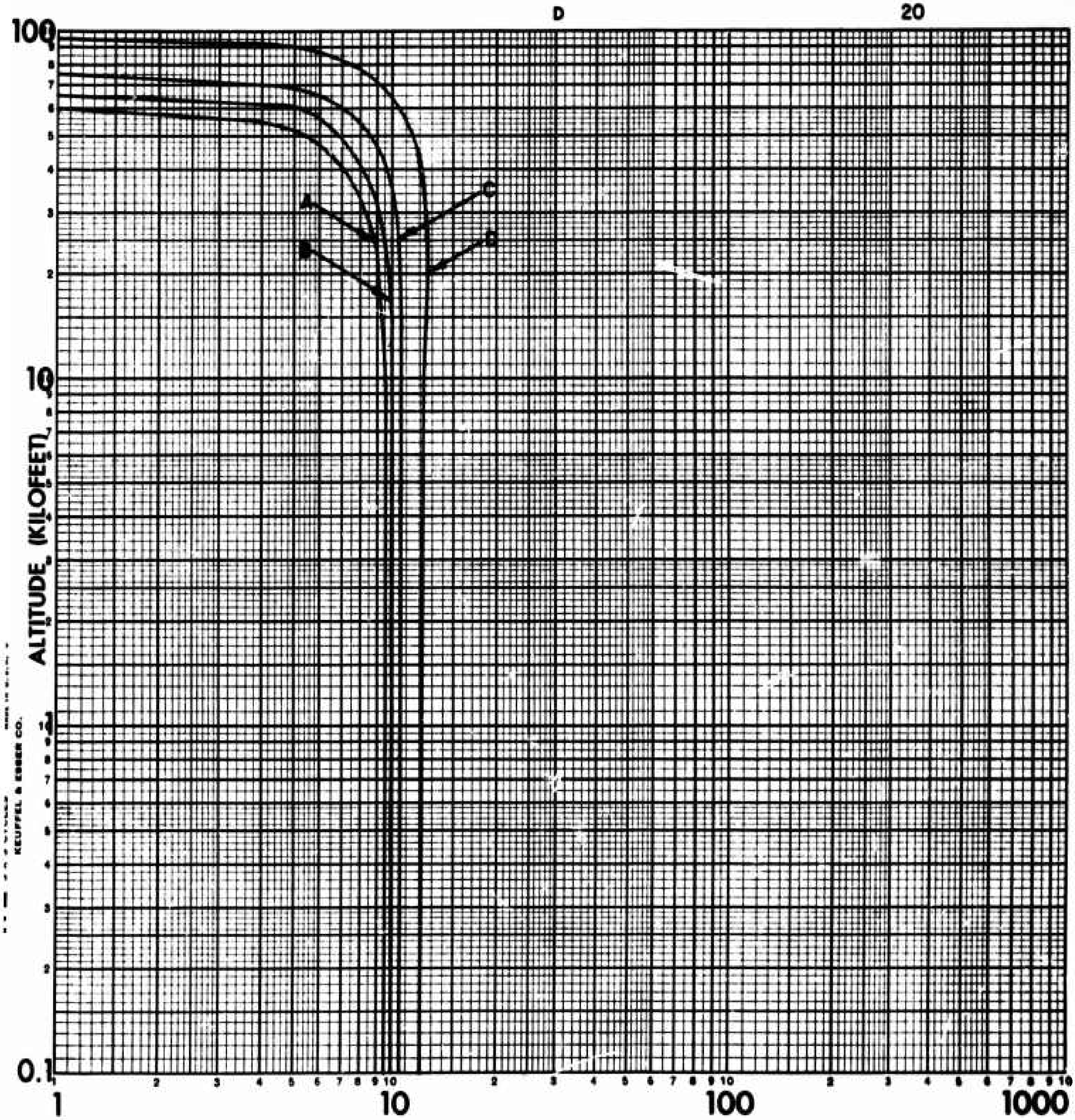


FIGURE 111

FLASHBLINDNESS

DAY MISSION

YIELD: 440 KT

FILTER: 2%

SYMBOL	BURST ALTITUDE (Kilofeet)
A	50
B	100
C	
D	

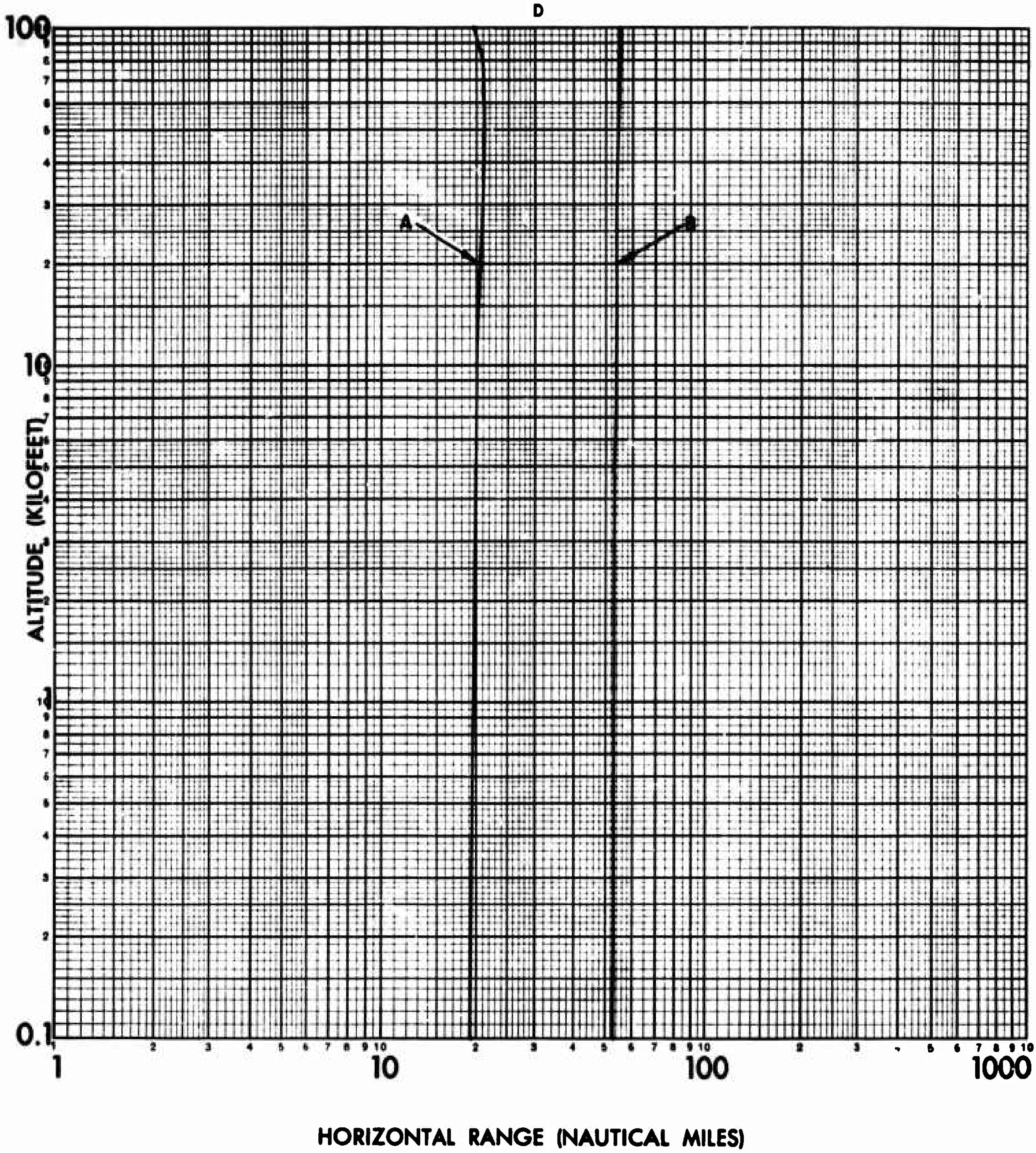


FIGURE 112

FLASHBLINDNESS

DAY MISSION

YIELD: 1000 KT

FILTER: 2 %

SYMBOL	BURST ALTITUDE (Kilofeet)
A	3
B	10
C	25
D	50

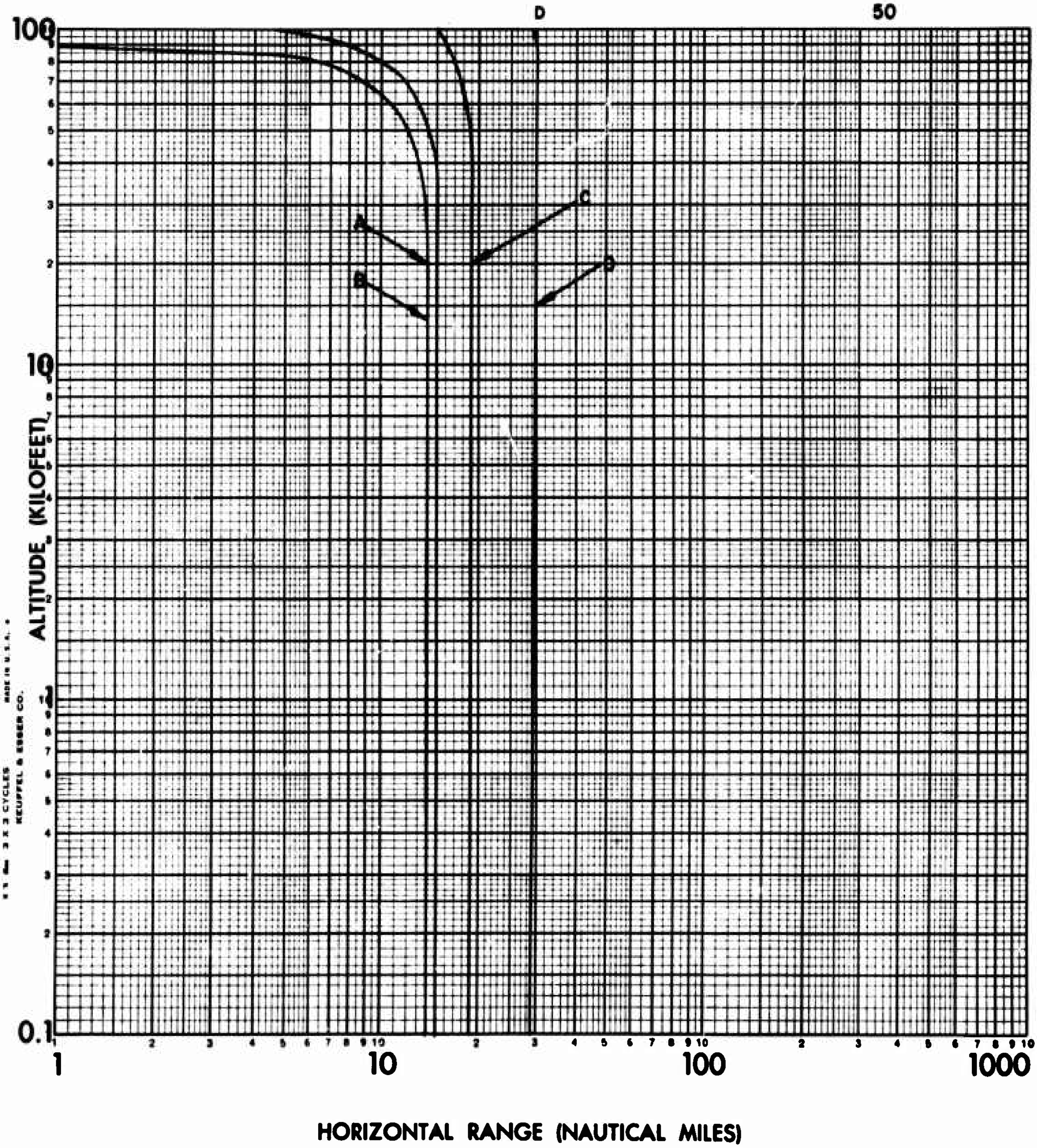


FIGURE 113

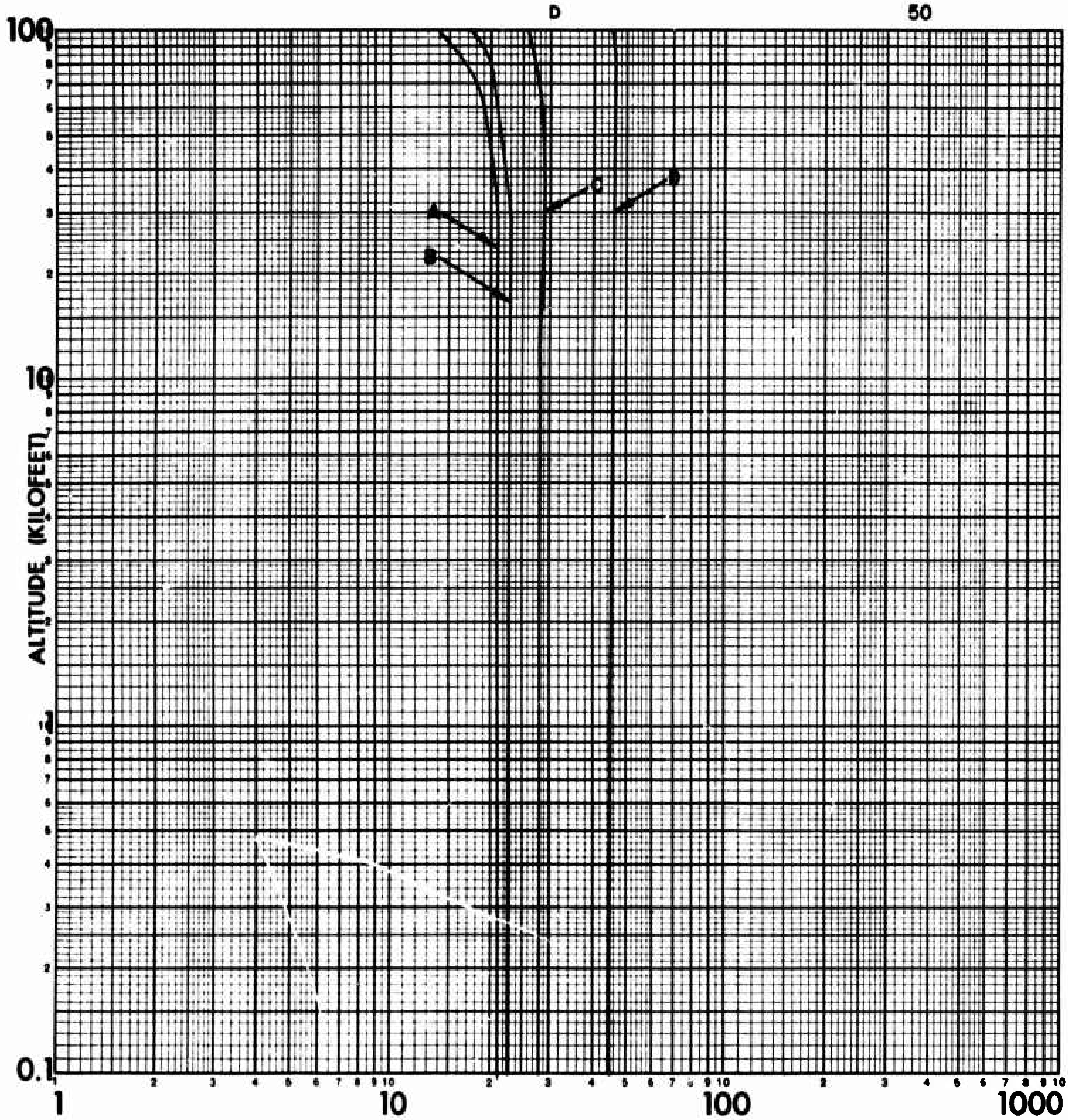
FLASHBLINDNESS

DAY MISSION

YIELD: 3800 KT

FILTER: 2%

SYMBOL	BURST ALTITUDE (Kilofeet)
A	4
B	10
C	25
D	50



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 114

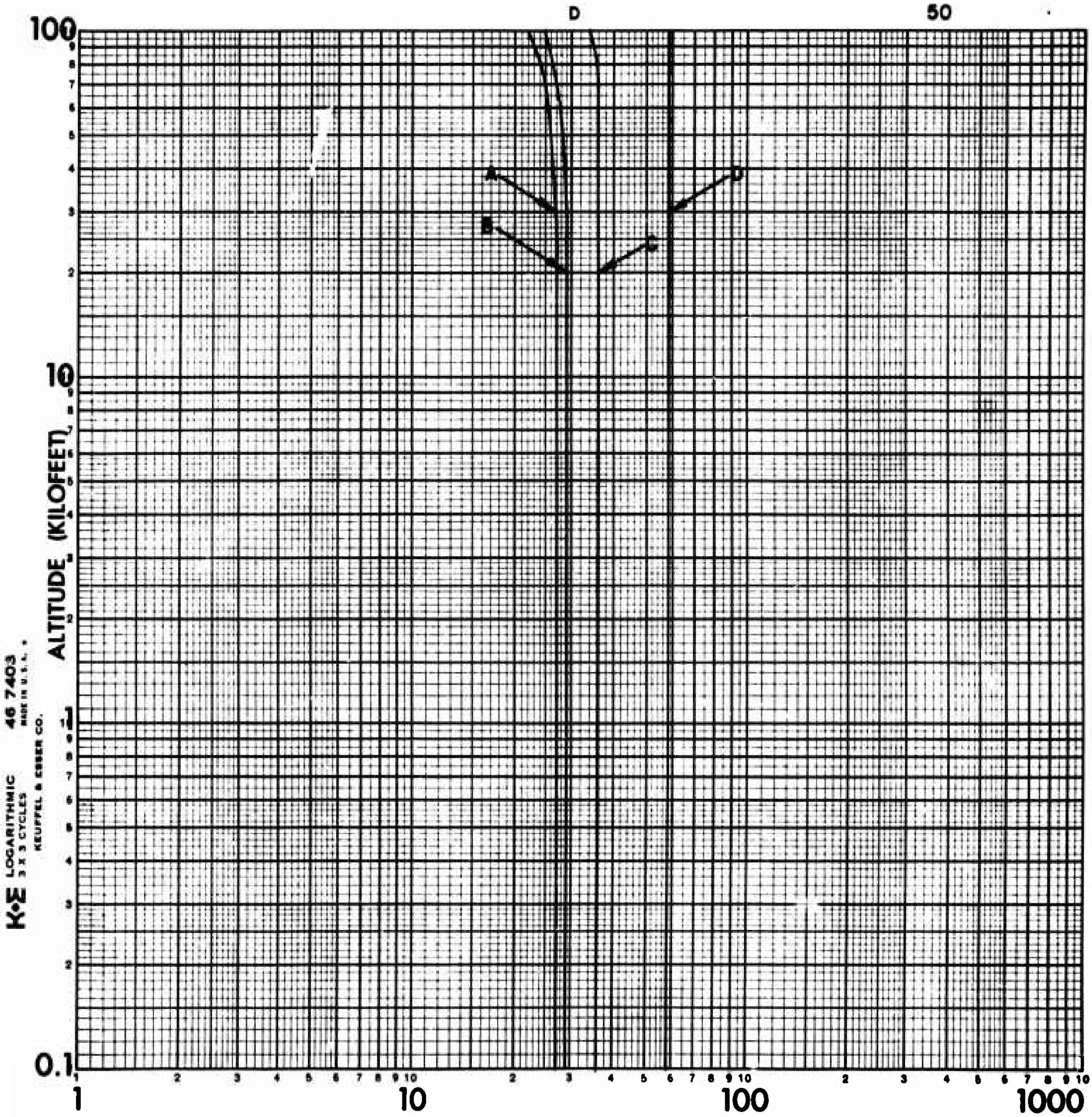
FLASHBLINDNESS

DAY MISSION

YIELD: 9000 KT

FILTER: 2%

SYMBOL	BURST ALTITUDE (Kilofeet)
A	5
B	10
C	25
D	50



HORIZONTAL RANGE (NAUTICAL MILES)

FIGURE 115

FLASHBLINDNESS

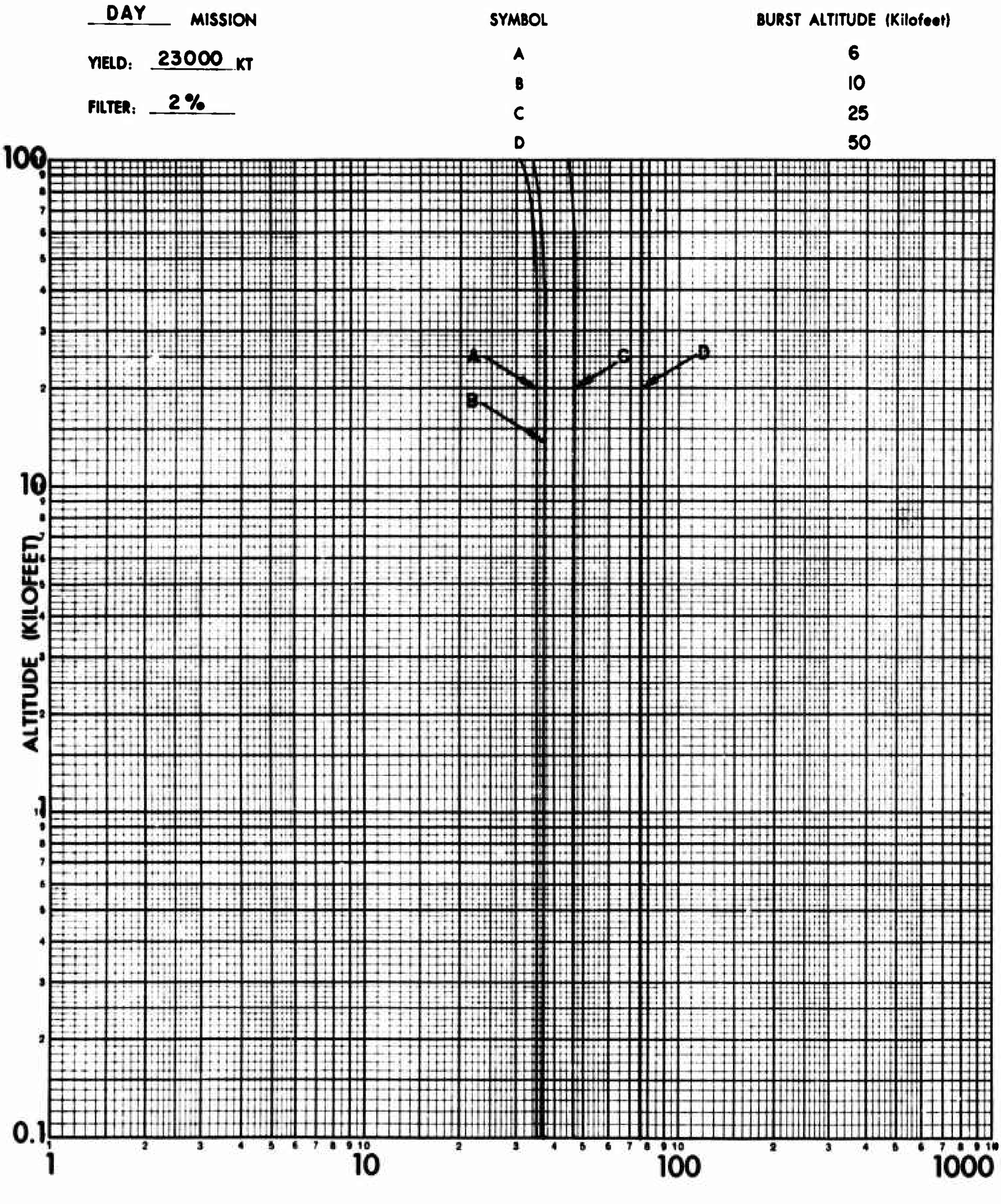


FIGURE 116

APPENDIX A

RETINAL BURN CALCULATIONS

APPENDIX A - RETINAL BURN CALCULATIONS

The method for calculating retinal burn envelopes is essentially an elaboration on the method of Allen and Richey [A-1][A-2]. Basically, the thermal energy given off by a fireball in the time necessary for the human eye to blink is calculated from the thermal characteristics of the weapon. This energy is attenuated by the atmosphere (air and water vapor), the aircraft canopy, pilot's visor, and the clear media of the eye and the retinal irradiance, Q_r, is determined as a function of distance from the fireball. These values are then compared to the allowable retinal exposure, Q_r^T, which has also been determined as a function of distance. The computer program which generates the envelopes given in this handbook uses a mathematical convergence technique to determine the allowable horizontal range, i.e., the distance measured along the surface of the earth at which $Q_r = Q_r^T$. A series of such calculations for several different observer altitudes defines one particular envelope.

The calculations given below are intended to illustrate the model used in the actual computer program and also to demonstrate a simplified technique which can be used to approximate threshold distances without the use of a computer. It should be noted that the approximation model described uses a so-called "flat-earth", i.e., the earth's curvature is not taken into account, whereas the computer program described in Appendix C takes into account the curvature of the earth. Generally, allowable horizontal ranges calculated

by the approximation method are somewhat greater than would be predicted by the computer program using the "round earth"-technique.

In order to hand-calculate an allowable horizontal range, the following parameters must be known in advance:

1. Blink Time, t_B (0.25 seconds for yield below 1000 KT; 0.45 seconds for 1000 KT and above).

2. Weapon yield, W, in kilotons.

3. Weapon burst height, H, in kilofeet (thousands of feet).

4. Observer altitude, A, in kilofeet.

5. f-stop of the human eye (f=6.8 for a day mission; f=2.6 for a night mission; f = 3.4 for a day mission with 2% gold visor).

The value for "k" (fraction of thermal radiation given off by the weapon in time t_B) is obtained from Figures A-1 or A-2. The sea level fireball diameter, DFB_o, is obtained from Figures A-3 or A-4, and the value is then corrected from sea level to the burst height H by:

$$DFB_H = DFB_o \times \sigma^{-1/3} \tag{1}$$

where

σ = ratio of the air density at height H to the standard sea level air density.

Table A-1 lists values of $\sigma^{-1/3}$ for several burst heights. A linear interpolation will suffice for any burst height not listed in this table.

The maximum anticipated retinal exposure, Q_r, is then calculated as a function of the horizontal distance, S, using the expression

$$Q_r\ (S) = 2 \left[\frac{a\ p\ k\ W\ T_e\ T_x \times 10^{12}}{4 \pi f^2\ (DFB_H)^2} \cdot T_a(S) \right] \quad (cal/cm^2) \qquad (2)$$

Here,

$Q_r(S) = 2Q_r(CALC)$, with the factor 2 introduced as an arbitrary safety factor*

$a = 0.79$ = Fraction of the thermal energy radiated which is located in the spectral region effective in producing retinal damage ($350\ m\mu < E < 1500\ m\mu$ assuming a 5800° K black-body radiator).

$p = 1/3$ = Fraction of total weapon yield converted to thermal energy (low-altitude detonations).

k = Fraction of thermal energy released during time t_B.

W = Yield of the weapon in kilotons.

$T_e = 0.8$ = Average transmission of clear media of the eye (assumed $5800\ ^{\circ}K$ black-body spectrum).

$T_a(S)$ = Average transmission of the atmosphere for horizontal distance S.

$T_x = 0.9$ = Maximum transmission of aircraft canopy or windows.

*Refer to page 22

$f = \frac{F}{d_p}$ = Ratio of the effective focal length of the eye-lens system to the diameter of the pupil.

DFB_H = Assumed average fireball diameter in centimeters during exposure time, t_B.

and

$$T_a(S) = \exp\left(-k_A^{eff} m\right) \times \exp\left(-k_w^{eff} w\right) . \qquad (3)$$

For $H \neq A$, i.e. for an observer altitude different than the altitude of the detonation,

$$m = \frac{\rho_{Ao}}{q_A(cm^{-1})} \; \frac{\left[(H-A)^2+S^2\right]^{1/2}}{|H-A|} \times \left| \exp\left[-q_A(kft^{-1})A\right] - \exp\left[-q_A(kft^{-1})H\right] \right| \qquad (4)$$

and

$$w = \frac{\rho_{wo}}{q_w(cm^{-1})} \; \frac{\left[(H-A)^2+S^2\right]^{1/2}}{|H-A|} \times \left| \exp\left[-q_w(kft^{-1})A\right] - \exp\left[-q_w(kft^{-1})H\right] \right| \qquad (5)$$

Here,

m = amount of air per unit area in path between the observer and the detonation in gm/cm^2.

w = amount of percipitable water (water vapor) in the path between the observer and the detonation in gm/cm^2.

k_A^{eff} = effective narrow-beam extinction coefficient for air

= 6.218×10^{-5} (cm^2/gm)

k_w^{eff} = effective narrow-beam extinction coefficient for water vapor

= 2.409×10^{-2} (cm^2/gm)

q_A = air lapse rate

= 0.041 (kilofoot^{-1}) = 1.34×10^{-6} (cm^{-1})

q_w = moisture lapse rate

= 0.1645 (kilofoot^{-1}) = 5.43×10^{-6} (cm^{-1})

ρ_{Ao} = sea level air density

= 1.4×10^{-3}) Typical of values measured over open water in the Pacific

ρ_{wo} = sea level water vapor density

= 2.2×10^{-5} (gm/cm^3) Typical of values measured over open water in the Pacific

For A = H, i.e. altitude of observer the same as the altitude of the detonation:

$$m = \rho_{Ao} \, e^{-q_A (kft^{-1}) A} \times S, \tag{6}$$

and

$$w = \rho_{wo} \, e^{-q_w (kft^{-1}) A} \times S \tag{7}$$

where S = distance between observer and detonation in centimeters.

The curve $Q_r(S)$ can be plotted as a function of the distance, S, on suitable paper and compared with the curve for the allowable retinal exposure $Q_r^T(S) = 1/4 Q_r^T(\text{MEAS})(S)$.

The curve $Q_r^T(S)$, extrapolated to humans as previously discussed, may be determined from laboratory measurements as follows:

1. Image diameters corresponding to various distances, S, are calculated from:

$$d_i(mm) = \frac{F \times \left| DFB_H(cm) \right| \times 3.28 \times 10^{-5}}{\left[S^2 + (H-A)^2 \right]^{1/2}}$$

where F = focal length of eye (17 mm).

DFB_H = fireball diameter, KILOFEET.

(H-A) = difference in burst and observer altitudes, KILOFEET.

S = horizontal range, KILOFEET.

2. From Figure A-5, determine values of Q_r^T(MEAS) for each d_i calculated. Values for Q_r^T(MEAS) may thus be found as a function of S. Q_r^T(MEAS) is then extrapolated to humans* through the relation $Q_r^T = 1/4 Q_r^T$(MEAS).

3. The allowable horizontal range, S, is the value at which the Q_r^T and Q_r curves intersect, i.e. the distance at which $Q_r^T = Q_r$.

Figure A-6 [(A-3)(A-4)] can be used to generate additional Q_r^T vs. d_i curves (for blink times, t_B, other than 250 and 450 msec) by merely sectioning the family of curves at the chosen blink time. The values of Q_r^T thus defined

*Refer to page 22

for the selected t_B can be plotted as a function of d_i--as in Figure A-5.

Because low yield weapons, up to 10 KT, release most of their energy well within the blink time, the allowable exposure, Q_r^T, was determined differently than for larger weapons. This is necessary since Q_r^T is a function of exposure time, and for low yield weapons, the effective exposure time is relatively short compared to a blink time of 0.25 seconds. The values of Q_r^T for low yield weapon were selected to correspond to an exposure time of $2t_{max}$, where t_{max} is the time to the second thermal maximum and is given approximately by $t_{max} = 0.032W^{0.5}$. Values of Q_r^T are then obtained from Figure A-4 as previously described.

EXAMPLE CALCULATION

1. **MISSION:** 100 KT Weapon; Burst Altitude = 2.7 kilofeet; Observer Altitude = 10 kilofeet; night mission (burst observed at night).

$W = 100$ KT, so that $t_B = 0.25$ seconds.

$H = 2.7$ KFT

$A = 10.0$ KFT

$d_p = 6.5$ mm, so that $f = \frac{F}{d_p} = \frac{17}{6.5} = 2.6$

From Figure A-3, $DFB_o = 6.89 \times 10^4$ cm

and $DFB_H = DFB_o \left[\sigma^{-1/3}\right]$

Interpolating from Table A-1, $\left[\sigma^{-1/3}\right] = 1.027$ at H = 2.7 KFT

So that $DFB_H = (6.89 \times 10^4)(1.027) = 7.1 \times 10^4$ cm

From Figure A-1, k = 0.22 at W = 100 KT and H = 2.7 KFT.

Then

$$Q_r = (2)\left[\frac{a\,p\,k\,W\,T_e\,T_x}{4\pi f^2 (DFB_H)^2} \cdot (10^{12})\right] T_a$$

$$= (2)\left[\frac{(0.79)(0.33)(0.22)(100)(0.8)(0.9)(10^{12})}{(4)(3.14)(2.6)^2(7.1 \times 10^4)^2}\right] T_a$$

$$Q_r = 2(9.65)T_a = 19.2T_a$$

$$T_a = \exp\left[-k_A^{eff}\, m\right] \cdot \exp\left[-k_w^{eff}\, w\right]$$

$$m = \frac{(1.4 \times 10^{-3})}{(1.34 \times 10^{-6})} \cdot \frac{\left[(2.7-10.0)^2 + S^2\right]^{1/2}}{|2.7-10.0|} \left| \exp(-0.041 \times 10.0) - \exp(-0.041 \times 2.7) \right|$$

$$m = 33.2 \left[53.3 + S^2 \right]^{1/2}$$

$$w = \frac{(2.2 \times 10^{-5})}{(5.43 \times 10^{-6})} \cdot \frac{\left[(2.7-10)^2 + S^2\right]^{1/2}}{|2.7-10.0|} \left| \exp(-0.1645 \times 10) - \exp(-0.1645 \times 2.7) \right|$$

$$w = 0.250 \left[53.3 + S^2 \right]^{1/2}$$

Substituting the expressions for m and w into the expression for T_a:

$$T_a = \exp\left[(-6.218 \times 10^{-5})(33.2) \left[53.3 + S^2\right]^{1/2} \right] \exp\left[(-2.409 \times 10^{-2})(0.250) \left[53.3 + S^2\right]^{1/2} \right]$$

$$T_a = \exp\left[(-0.00808) \left[53.3 + S^2\right]^{1/2} \right]$$

Substituting this expression for T_a into the equation for Q_r:

$$Q_r = 19.2 \exp\left[(-0.00808) \left[53.3 + S^2\right]^{1/2} \right]$$

Now it merely remains to substitute values into this expression to obtain coordinates to plot Q_r vs. S. The table below lists a few such values which are in turn plotted in Figure A-7.

Horizontal Range, S (kilofeet)	Retinal Exposure, Q_r (cal/cm^2)
0	18.2
1	18.2
5	18.0
10	17.5
50	12.8
100	8.58
200	3.86
500	0.374
1000	0.00864

To generate a Q_r^T vs. S curve to intersect with the above Q_r vs. S curve, we calculate d_i for various values of S from

$$d_i\,(\text{mm}) = \frac{F \times DFB_H\,(\text{cm}) \times 3.28 \times 10^{-5}}{\left[S^2 + (H-A)^2\right]^{1/2}}$$

and get Q_r^T(MEAS) values for each S from Figure A-5.

Values for $Q_r^T = 1/4 Q_r^T$(MEAS) for various values of S are listed below and the curve Q_r^T vs S is shown in Figure A-7.

Horizontal Range, S (kilofeet)	Retinal Image Diam, d_i (mm)	Allowable Retinal Exposure (cal/cm^2)
0	5.42	.24
1	5.36	.24
5	4.47	.25
10	3.19	.26
50	0.783	.37
100	0.396	.57
200	0.198	1.8
500	0.0792	9.5

The intersection of the two curves is at approximately 260 KFT or 43 nautical miles. This is the required distance, S_A, and shows that an observer at 10,000 feet altitude could safely venture no closer than 43 nm (horizontal range) to a 100 KT weapon detonated at 2700 feet - AT NIGHT. (In the day time, the pupil would not be as large, thus permitting less energy into the eye. This would allow the observer to approach somewhat closer to the same burst.)

2. MISSION: 1000 KT (1 MT) Weapon; Burst Altitude = 5.0 KFT; Observer Altitude = 0 KFT; Day Mission (Burst observed during daylight)

$W = 1000\,KT$, so that $t_B = 0.45$ seconds

$H = 5.0\,KFT$

$A = 0.0\,KFT$

$d_p = 2.5$ mm, so that $f = \frac{17}{2.5} = 6.8$

From Figure A-4, $DFB_o = 1.56 \times 10^5$ cm

and

$$DFB_H = DFB_o \left[\sigma^{-1/3}\right]$$

From Table A-1, $\left[\sigma^{-1/3}\right] = 1.05$ at $H = 5.0$ KFT

So that $DFB_H = (1.56 \times 10^5)(1.05) = 1.64 \times 10^5$ cm

From Figure A-2, $k = 0.07$ at $W = 1000$ KT and $H = 5.0$ kft

Then

$$Q_r = (2)\left[\frac{(0.79)(0.33)(0.07)(1000)(0.8)(0.9)(10^{12})}{(4)(3.14)(6.8)^2(1.64 \times 10^5)^2}\right] T_a$$

$$Q_r = 2(0.841)\,T_a = 1.68\,T_a$$

$$T_a = \exp\left[-k_A^{eff} m\right] \quad \exp\left[-k_w^{eff} w\right]$$

$$m = \frac{(1.4 \times 10^{-3})}{(1.34 \times 10^{-6})} \cdot \frac{\left[(5.0-0)^2 + S^2\right]^{1/2}}{|5.0-0|} \cdot \left|\exp(-0.041 \times 0) - \exp(-0.041 \times 5.0)\right|$$

$$m = 38.9\left[25 + S^2\right]^{1/2}$$

$$w = \frac{(2.2 \times 10^{-5})}{(5.43 \times 10^{-6})} \cdot \frac{\left[(5.0-0)^2 + S^2\right]^{1/2}}{|5.0-0|} \cdot \left|\exp(-0.1645 \times 0) - \exp(-0.1645 \times 5.0)\right|$$

$$w = 0.454\left[25 + S^2\right]^{1/2}$$

Substituting the expressions for m and w into the expression for T_a:

$$T_a = \exp\left[(-6.218\times10^{-5})(38.9)\left[25+S^2\right]^{1/2}\right]\exp\left[(-2.409\times10^{-2})(0.454)\left[25+S^2\right]^{1/2}\right]$$

$$T_a = \exp\left[(-0.0134)\left[25+S^2\right]^{1/2}\right]$$

Thus $Q_r = (1.68)\ \exp\left[(-0.0134)\left[25+S^2\right]^{1/2}\right]$

We again obtain a table as in the previous example by substituting values of S in this expression for Q_r. The table below lists such values which are plotted in Figure A-8.

Horizontal Range, S (kilofeet)	Retinal Exposure, Q_r (cal/cm^2)
0	1.58
1	1.58
5	1.54
10	1.45
50	0.86
100	0.44
200	0.12
500	0.0014

We again calculate values of d_i from:

$$d_i(\mathrm{mm}) = \frac{F\ \ DFB_H(\mathrm{cm}) \times 3.28 \times 10^{-5}}{\left[S^2 + (H-A)^2\right]^{1/2}}$$

and refer to Figure A-5 for values of Q_r^T for each S.

Horizontal Range, S (kilofeet)	Retinal Image Diam., d_i (mm)	Allowable Retinal Exposure, Q_r^T (cal/cm^2)
10	7.75	0.39
50	1.82	0.41
100	0.91	0.48
200	0.46	0.80
500	0.18	3.60

These values are plotted in Figure A-8 to obtain an intersecting curve with the Q_r vs. S plot. The curves intersect at S = 95 KFT or about 16 nautical miles. For this case, then, an observer at sea level can safely venture no closer than 16 nm (horizontal range) to a 1 MT burst at 5000 feet - IN THE DAYTIME. In this particular example, it is likely that other criteria (radiation, etc.) may prohibit the observer's approaching this close so that the production of retinal burns may not be the limiting factor.

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A-4. Richey, Everett O. Prediction of eye safe separation distances. Presented at AGARD Symposium on Loss of Vision from High Intensity Light, Paris, France, March 1966.

TABLE A-1

Fireball diameter altitude scaling factors

H, kft	$\sigma^{-1/3}$	H, kft	$\sigma^{-1/3}$	H, kft	$\sigma^{-1/3}$
0	1.0000	41	1.6214	81	3.0718
1	1.0098	42	1.6475	82	3.1208
2	1.0198	43	1.6742	83	3.1697
3	1.0300	44	1.7012	84	3.2219
4	1.0403	45	1.7286	85	3.2737
5	1.0509	46	1.7565	86	3.3251
6	1.0616	47	1.7851	87	3.3798
7	1.0725	48	1.8137	88	3.4337
8	1.0835	49	1.8431	89	3.4863
9	1.0948	50	1.8729	90	3.5474
10	1.1062				
		51	1.9030	91	3.6019
11	1.1180	52	1.9337	92	3.6598
12	1.1298	53	1.9650	93	3.7152
13	1.1420	54	1.9968	94	3.7742
14	1.1544	55	2.0291	95	3.8371
15	1.1670	56	2.0617	96	3.8967
16	1.1797	57	2.0953	97	3.9603
17	1.1928	58	2.1292	98	4.0281
18	1.2061	59	2.1631	99	4.0916
19	1.2196	60	2.1985	100	4.1590
20	1.2334				
		61	2.2339		
21	1.2475	62	2.2699		
22	1.2619	63	2.3064		
23	1.2766	64	2.3434		
24	1.2914	65	2.3819		
25	1.3068	66	2.4184		
26	1.3223	67	2.4572		
27	1.3382	68	2.4974		
28	1.3544	69	2.5375		
29	1.3709	70	2.5774		
30	1.3878				
		71	2.6184		
31	1.4050	72	2.6605		
32	1.4226	73	2.7036		
33	1.4405	74	2.7478		
34	1.4589	75	2.7909		
35	1.4777	76	2.8369		
36	1.4969	77	2.8814		
37	1.5206	78	2.9289		
38	1.5452	79	2.9744		
39	1.5702	80	3.0229		
40	1.5955				

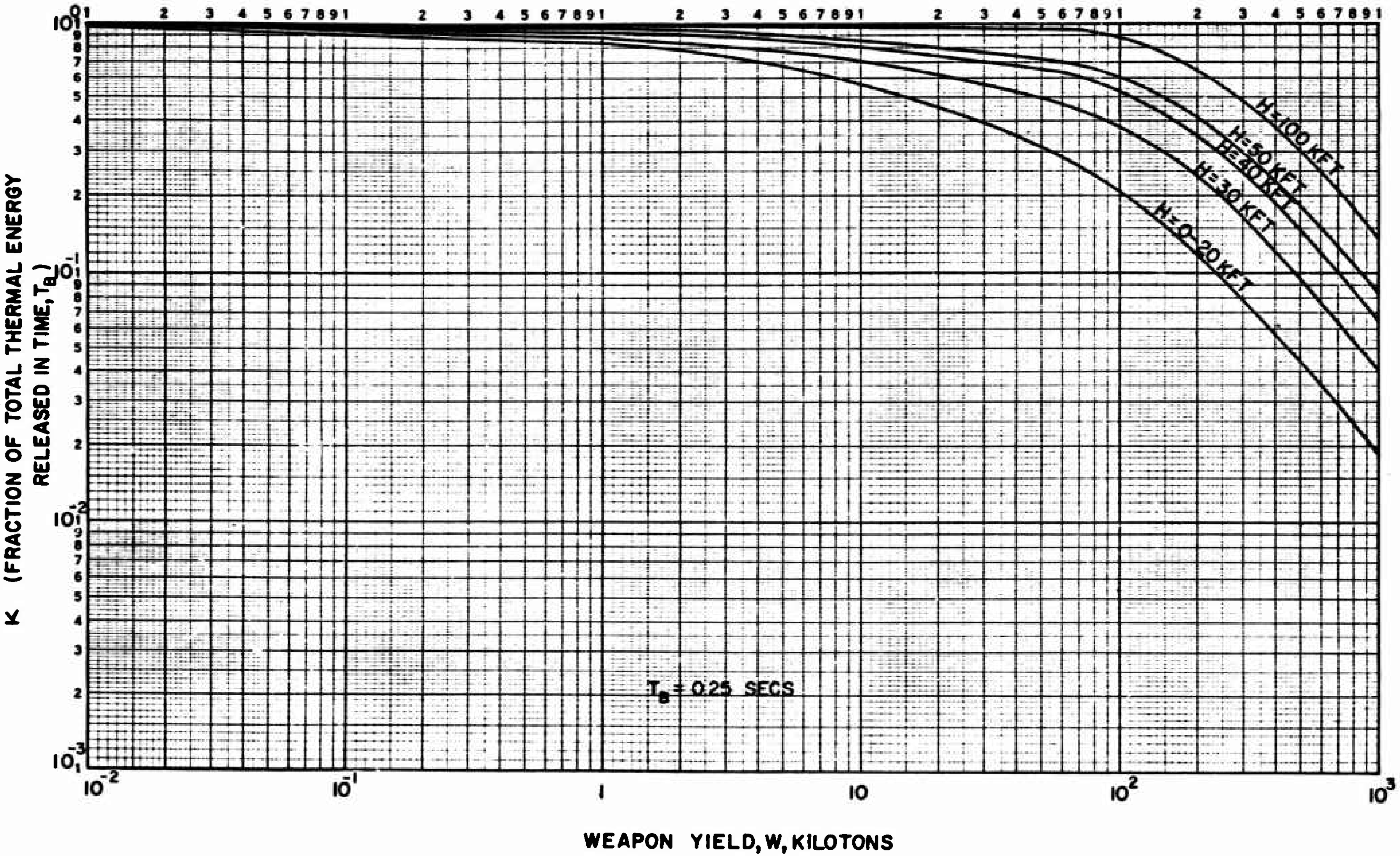

FIGURE A-1. Fraction of total thermal energy released in blink time as a function of yield and burst altitude.

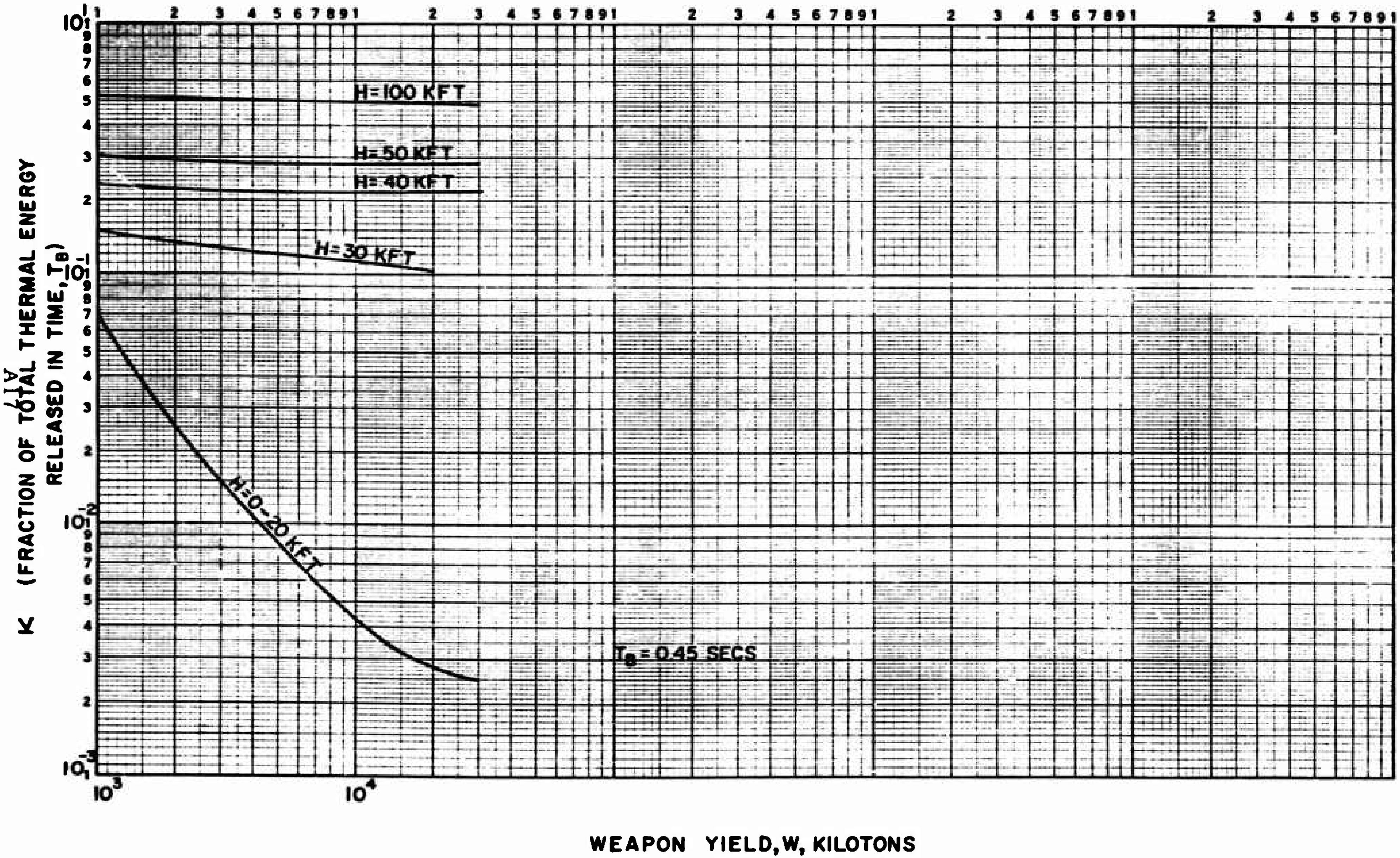

FIGURE A-2. Fraction of total thermal energy released in blink time as a function of yield and burst altitude.

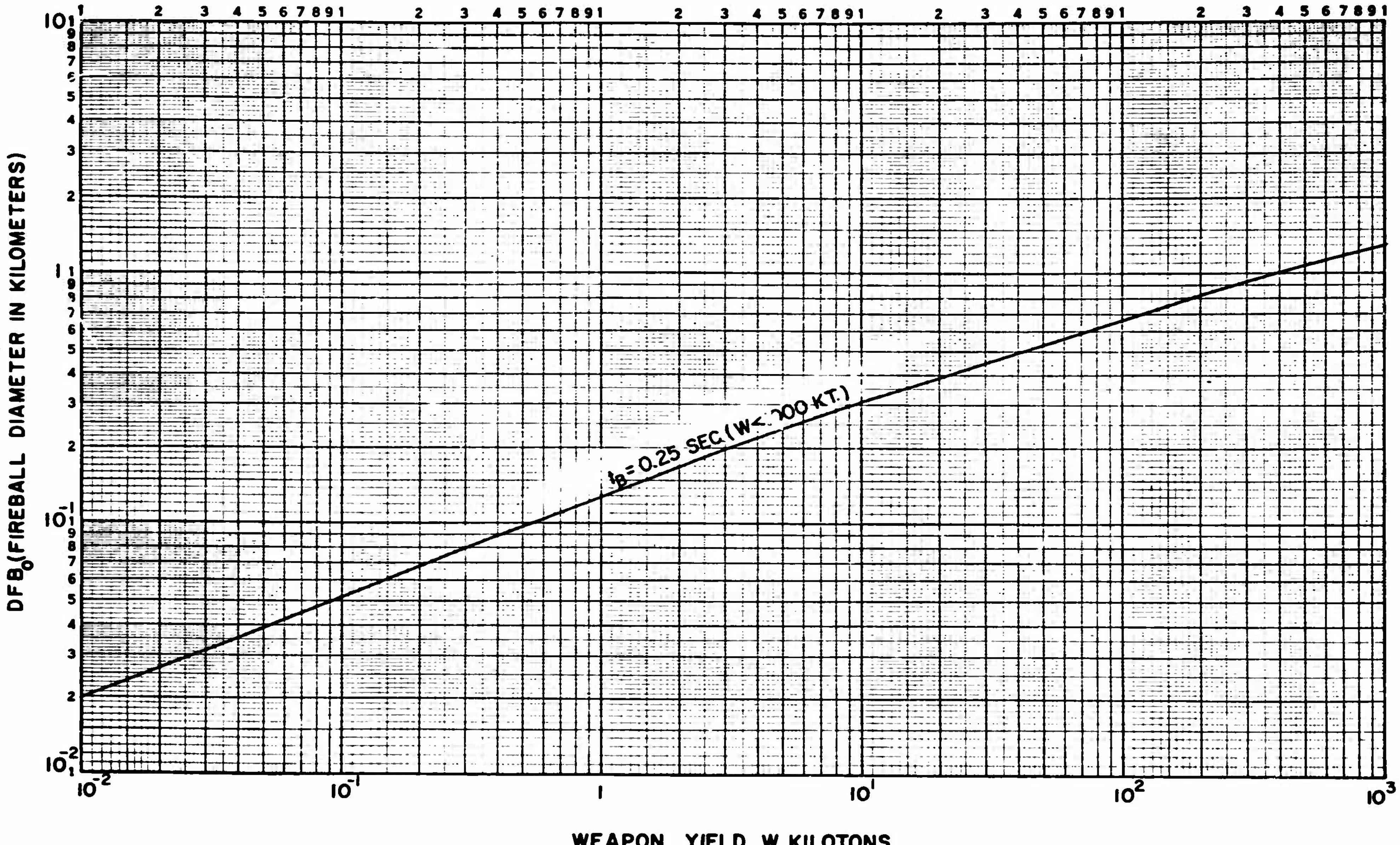

FIGURE A-3. Fireball diameter as a function of yield at $T_B = 0.25$ seconds

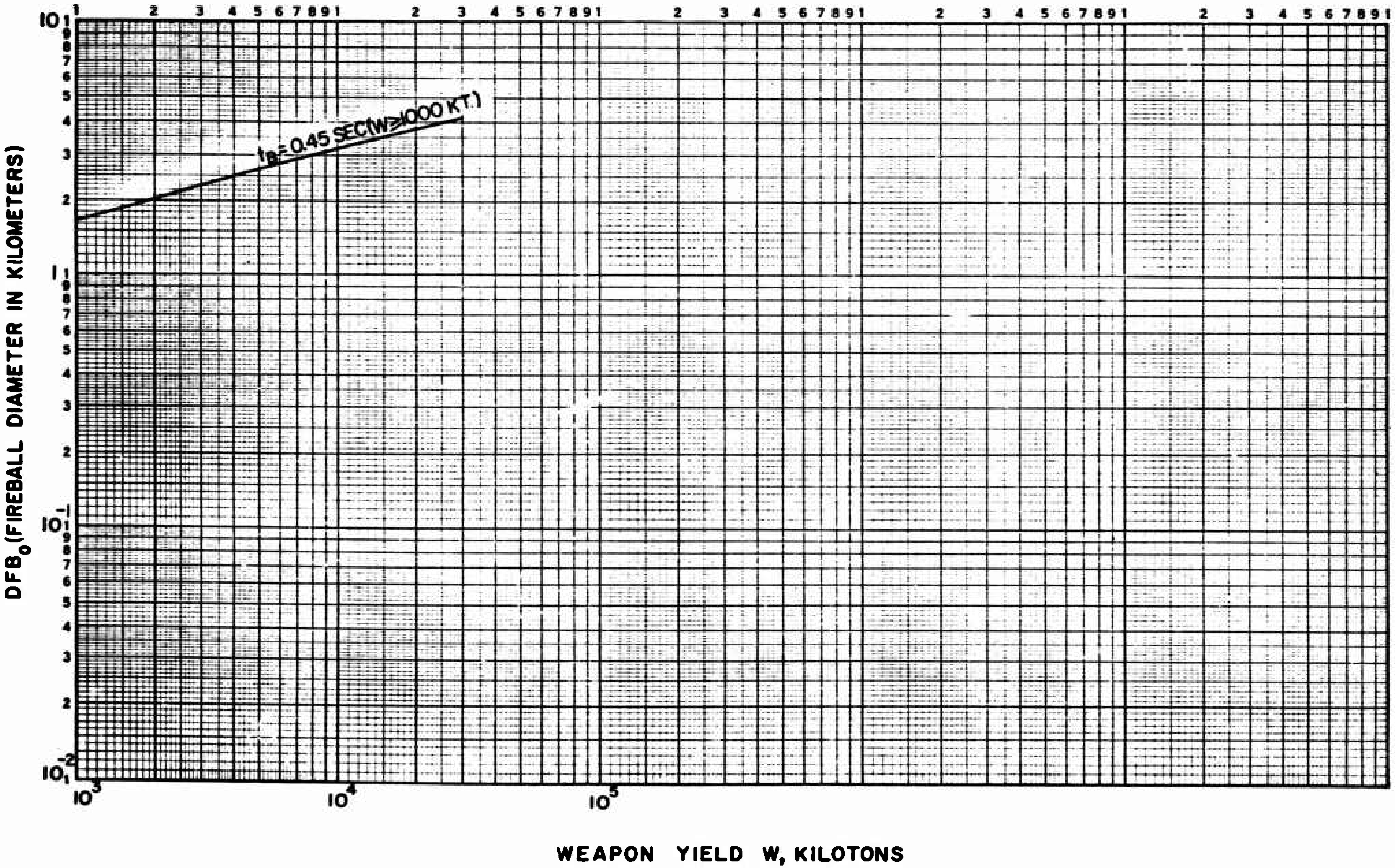

FIGURE A-4. Fireball diameter as a function of yield at $T_B = 0.45$ seconds

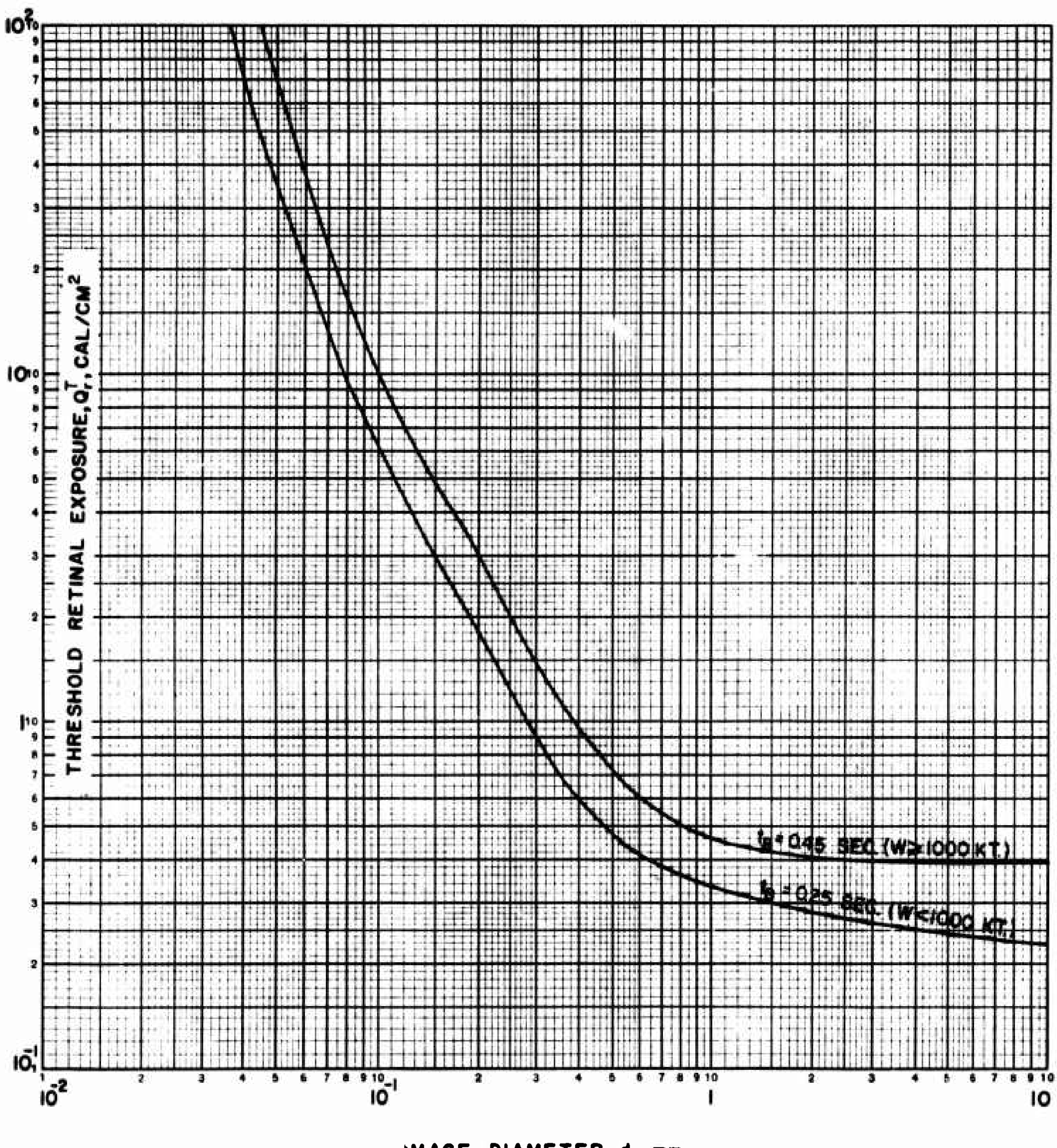

FIGURE A-5. Threshold retinal exposure as a function of image diameter for two blink times

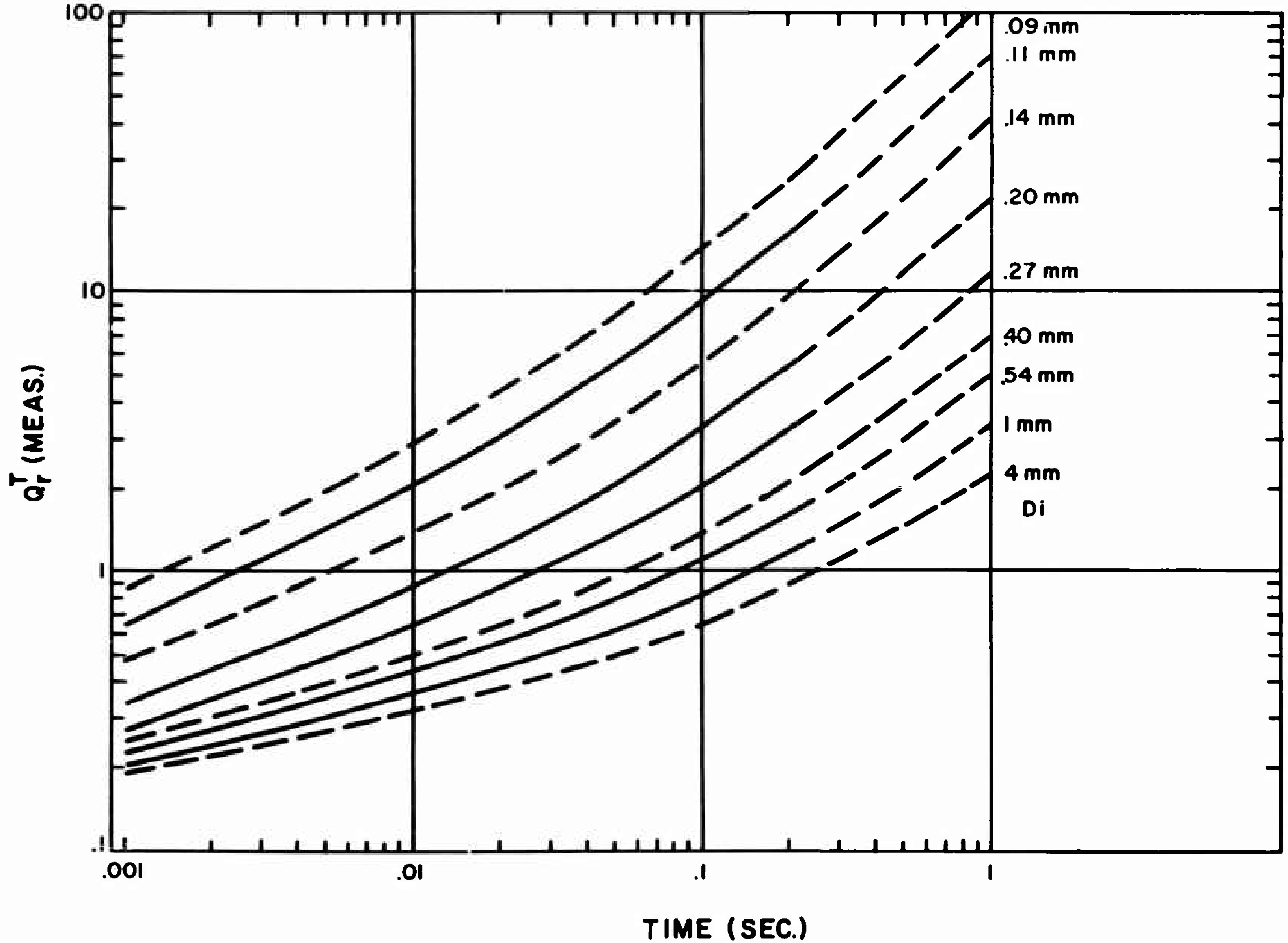

FIGURE A-6. Q_r^T(MEAS) as a function of exposure time and image diameter.

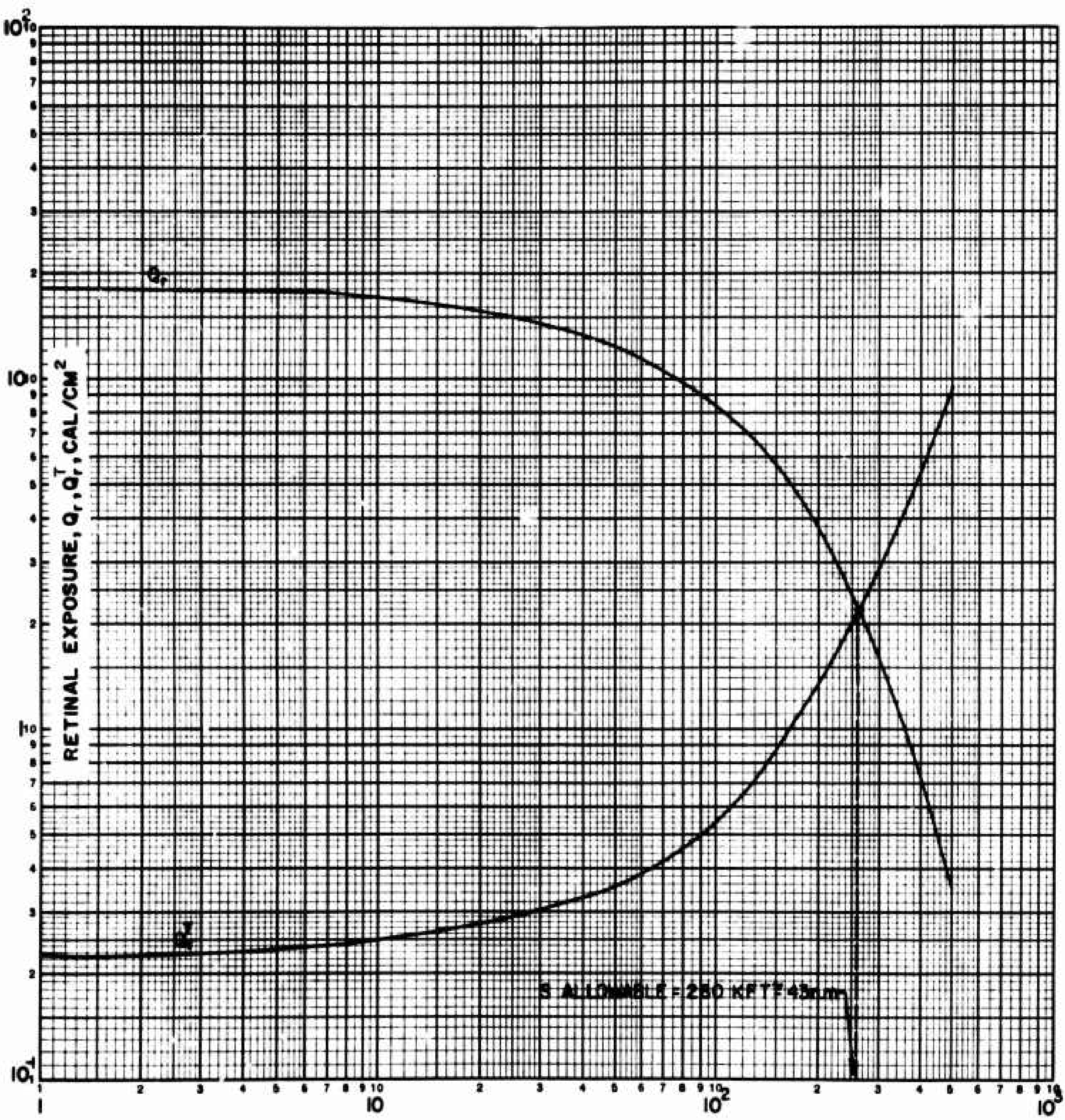

FIGURE A-7. Determination of safe separation distance

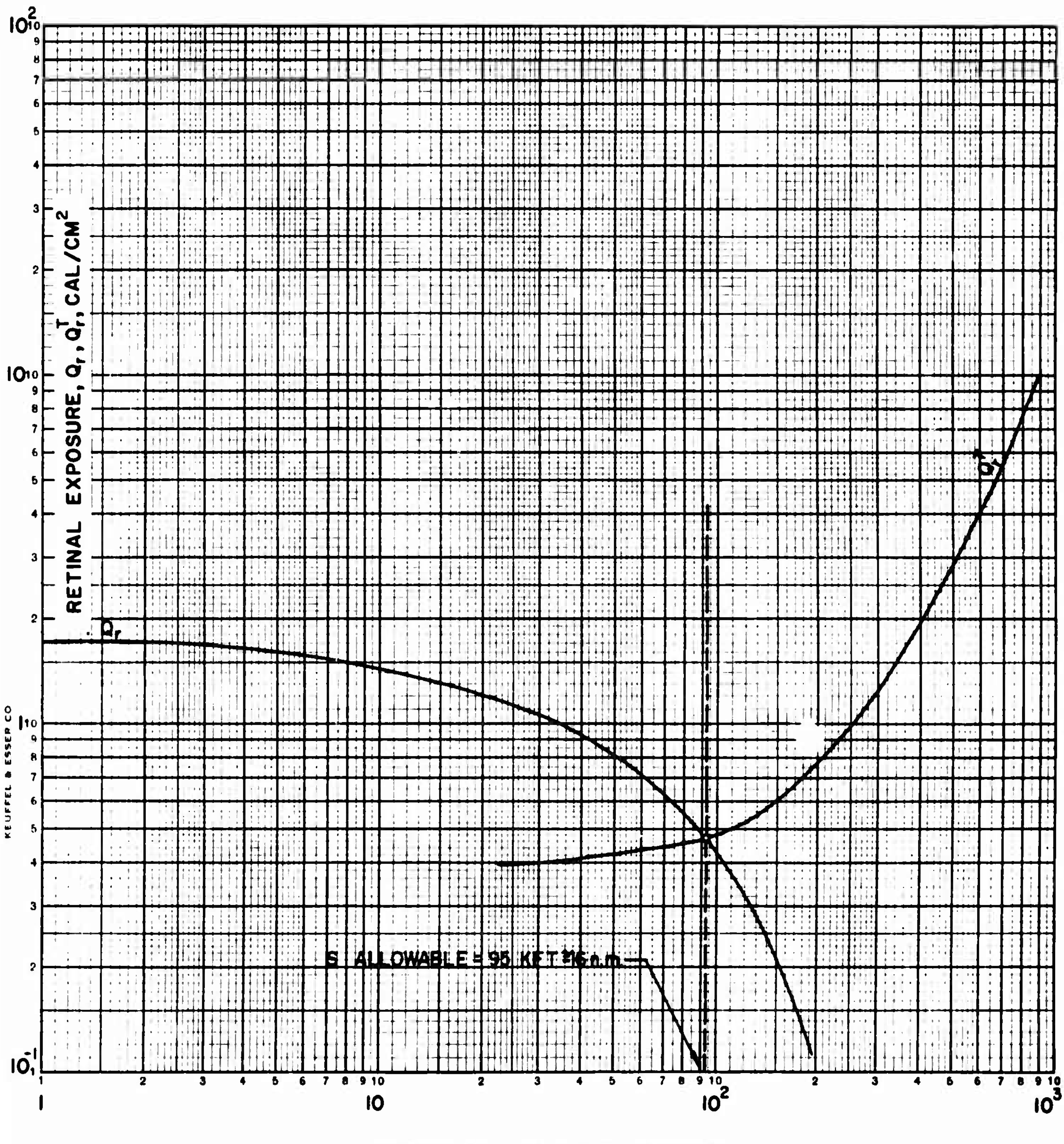

FIGURE A-8. Determination of safe separation distance

APPENDIX B

FLASHBLINDNESS CALCULATIONS

APPENDIX B - FLASHBLINDNESS CALCULATIONS

The problem of determining the degree of flashblindness, or the time required to recover a specified visual acuity after exposure to a high-luminance source, is inherently more complicated than the problem of determining the occurrence or non-occurrence of a retinal burn of significant dimensions. The additional complexity arises because the diffusely scattered light cannot be ignored in the determination of flashblindness-as it was in the case of retinal burns. Three factors influence the calculation of an acceptable separation distance--image size, image exposure, and extra-image exposure. Richey[B-1], in examining the effect of image size on flashblindness, viewed a standard altimeter at a distance of 30 inches--average eye-to-instrument distance in fighter aircraft--following exposure to centrally fixated flashes of bright light. He reported no difficulty in reading the altimeter when the afterimages subtended visual angles of 3^{o} or less (image diameters of 0.9mm or less) even when individual numbers, when fixated directly, could not be identified through the afterimages. In view of these results, a focused image on the fovea less than about 1.0 millimeter in diameter has been considered to have no significant effect on a pilot's ability to extract useful information from his instruments, at least for instruments similar to the altimeter. However, depending upon the magnitude of the exposure, afterimages larger than 1.0mm can interfere with visual acuity. The maximum allowable exposure, E_r^A, is based on the recovery, within 10 seconds, of a visual acuitv of 20/120. For night situations, instrument luminance was taken to be 0.07 millilamberts[B-2]. For day exposures, an average instrument luminance of

20 millilamberts[B-3] was used.

According to Miller[B-4], the corresponding foveal exposures, E_r^M, that correspond to a 10 second recovery time are 1.0×10^6 troland-seconds for the night condition and 2.5×10^7 troland-seconds for the day situation.

As in the calculation of retinal burns, safety factors have been introduced to account for variations between individuals. The "allowable" value, E_r^A, is obtained by reducing E_r^M, the measured value, by a factor of 2, i.e. $E_r^A = E_r^M/2$.

In addition, the calculated luminous exposure, $E_r(CALC)$, has been arbitrarily increased by a factor of 2 to allow for inaccuracies which may have been introduced by the model used. Thus, the "safe-sided" value is obtained from the equation $E_r = 2E_r(CALC)$.

The many variables of the problem and the state-of-the-art concerning the calculation of luminous exposure suggest the use of a "worst-case" philosophy in dealing with flashblindness. Since the maximum exposure will occur within the retinal area covered by the image, and since central vision is of primary concern, the worst case consists of direct foveal viewing of the fireball--i.e. an image of the fireball centered in or upon the fovea.

In view of the significance of image size, the following criteria have been introduced:

a) If the image diameter is greater than or equal to one millimeter, the foveal exposure will be determined by the imaged or focused energy.

b) If the image diameter is less than one millimeter, the foveal exposure will be determined by the extra-image or scattered energy.

In each case, the horizontal distance of nearest approach is determined by the condition $E_r = E_r^A$.

The first step in determining the "allowable" distance is the calculation of the horizontal distance (S_1) at which the image diameter at assumed blink time is 1 millimeter. As in the case for retinal burns, blink time is assumed to be 0.25 seconds for weapon yields less than one megaton and 0.45 seconds for yields of one megaton or larger. The retinal exposure in the image, E_r^i, at distance S_1 is then calculated:

a) If $E_r^i(S_1) < E_r^A$, E_r^i is calculated as a function of decreasing distance (S) until $E_r^i(S) = E_r^A$. The horizontal distance (S) at which $E_r^i(S) = E_r^A$ is taken to be the nearest allowable approach distance.

b) If $E_r^i(S_1) = E_r^A$, S_1 is the "allowable" distance.

c) If $E_r^i(S_1) > E_r^A$, the extra-image exposure, E_r^x, becomes of concern. The value E_r^x is then calculated as a function of increasing distance (S), using the model developed by Vos [(B-5)(B-6)], until $E_r^x(S) = E_r^A$. Since E_r^x is a function of position on the retina relative to the center of the image, it was necessary to select an appropriate retinal position for the calculation of E_r^x. This position was selected to correspond to the edge of a one millimeter image, i.e. approximately

1.5^{o} degrees from the direction defining the center of the image. (By the conventions adopted, the direction defining the center of the image is also the direction of fixation.)

This selection insures a recovery of 20/120 acuity, within 10 seconds, in the fovea adjacent to, but outside of a one millimeter diameter area--regardless of the circumstances of the exposure. On the basis of Richey's[(B-1)] experience, this will permit extraction of useful information from most aircraft instruments within 10 seconds.

Calculation Methods

A. Exposure due to direct image radiation

The concepts and equations used in calculating flashblindness in the direct image are essentially the same as those used in calculating retinal burns. However, the luminous exposure in the direct image is of interest only when the image diameter is equal to or greater than one millimeter. In this case, the calculation of luminous exposure is carried out as described in Appendix A, with E_r (troland-seconds) obtained from Q_r (cal/cm^2) using the relationship

$$E_r^i(\text{troland-secs}) = \frac{680 \times 10^4 (F)^2 \bar{R}\, Q_r(\text{watt-sec/cm}^2)}{T_e} \qquad (1)$$

$$= 1.54 \times 10^9\, Q_r(\text{cal/cm}^2)$$

where:

F = effective focal length of eye in mm (17mm).

T_e = average transmission of the clear media of the eye (0.8).

$$\bar{R} = \frac{\int_0^{\infty} V(\lambda)\, N(\lambda)\, d(\lambda)}{\int_0^{\infty} N(\lambda)\, d(\lambda)} = 0.15$$

$V(\lambda)$ = relative photopic luminous efficiency

$N(\lambda)$ = spectral radiance of the fireball in watts/cm^2-steradian-mμ

λ = wavelength of incident radiation in mμ

B. Exposure resulting from scattered radiation

Calculation of the extra-image exposure, adapted from the model developed by Vos(B-5)(B-6), is based on the following assumptions:

1) With respect to the diffusely scattered light, the fireball is considered to be a point source.

2) The luminous exposure resulting from the scattered light depends upon the amount of radiant energy entering the eye, hence, varies inversely with the square of the distance between source and observer.

3) The extra-image exposure at a particular position on the retina depends upon the distance of the retinal position in question from the center of the geometrical image of the fireball.

4. Three components of indirect light are responsible for extra-image exposure:

   a) Intra-ocular scattering (E^{x}_{Io}).

   b) Scattering of light by the atmosphere (E^{x}_{At}).

   c) Diffusely reflected light from the earth's surface (ground or water) and clouds (E^{x}_{Cl}).

The contributions of these three components in troland-seconds, adapted from those described by Vos, are:

	Day	Night
$E^{x}_{Io}(CALC) =$	$\dfrac{110\ c^2\ E_c}{D^2\ \alpha^2}$	$\dfrac{675\ c^2\ E_c}{D^2\ \alpha^2}$
$E^{x}_{At}(CALC) =$	$\dfrac{40\ c^2\ E_c}{D^2\ \alpha}$	$\dfrac{240\ c^2\ E_c}{D^2\alpha}$
$E^{x}_{Cl}(CALC) =$	$\dfrac{2\ c^2\ E_c}{D^2}$	$\dfrac{13\ c^2\ E_c}{D^2}$

Combining these three expressions into one, and correcting for atmospheric transmission yields

Day

$$E^{x}_{r}(CALC) = \frac{c^2}{D^2}\ T_a(D) \cdot T_e \cdot T_x \left(\frac{110}{\alpha^2} + \frac{40}{\alpha} + 2\right) E_c$$

Night

$$E^{x}_{r}(CALC) = \frac{c^2}{D^2}\ T_a(D) \cdot T_e \cdot T_x \left(\frac{675}{\alpha^2} + \frac{240}{\alpha} + 13\right) E_c \qquad (2)$$

where:

$c = 4920\ W^{0.33}$ feet

W = yield in kilotons

$T_e = 0.8$ = average transmission of clear media of the eye (assumed 5800° K black-body spectrum).

$T_x = 0.9$ = maximum transmission of aircraft canopy or windows.

The expression for c is an empirical expression derived by Vos to describe a critical distance of approach and serves here only as a reference distance in extrapolating to other distances.

D = slant range from the fireball to the observer, in feet.

E_r^x(CALC) = extra-image exposure in troland-seconds.

E_c = integrated illumination in lux-seconds at c, the critical distance.

$T_a(D)$ = average transmission of the atmosphere for the slant range D.

α = distance of the retinal position from the center of the geometrical image of the fireball at which the extra-image exposure is being calculated.

The integrated illumination, E_c, at the critical distance, can be determined from the integrated luminance of the fireball from

$$E_c = \frac{1}{c^2} \int_0^{t_b} \pi B(t) R^2(t)\, dt, \tag{3}$$

with $c = 1500\ W^{0.33}$ meters and t_b = blink time. (4)

Combining equations (3) and (4),

$$E_c = 4.5 \times 10^{-7}\ W^{-0.67} \int_o^{t_b} \pi\, B(t) R^2(t)\, dt. \tag{5}$$

Since, $t = t_s W^{0.5}$ and $dt = dt_s\ W^{0.5}$,

$$\int_o^{t_b} \pi\, B(t) R^2(t)\, dt = W^{1.3} \int_o^{t_b W^{-0.5}} \pi\, \rho^2 (t_s)\, B(t_s)\, dt_s. \tag{6}$$

$$\therefore E_c = 4.5 \times 10^{-7} W^{0.63} \int_o^{t_b W^{-0.5}} \pi \rho^2 (t_s)\, B(t_s)\, dt_s \tag{7}$$

where

$R(t_s)$ = radius of the fireball, meters

$B(t_s)$ = luminance of fireball

W = yield in kilotons

$t_s = tW^{-0.5}$ = scaled time

$\rho = RW^{-0.4}$ = scaled fireball radius

The quantity $\int_o^{t_b W^{-0.5}} \pi\rho^2 (t_s) B(t_s) dt_s$, corresponding to blink times of 0.25 and 0.45 seconds, can be obtained from Figures B-1 and B-2, and E_c can then be determined using equation (7).

The value of F_c, used in equation 2, with $\alpha = 1.5^{o}$, gives $E_r^x(\text{CALC})$. E_r^x is obtained from $E_r^x = 2E_r^x(\text{CALC})$ and the distance at which $E_r^x = E_r^A$ defines the allowable distance of nearest approach.

REFERENCES

B-1. Richey, Everett O. Prediction of eye safe separation distances. Presented at AGARD Symposium on Loss of Vision from High Intensity Light, Paris, France, March 1966.

B-2. Handbook for Instructions for Aerospace Personnel Subsystem Design (HIAPSD), AFSC Manual 80-3, 1 July 1961, Reprint 15 April 1965.

B-3. Pitts, D. G and L. R. Loper. Ambient and cockpit luminance measurements. Vision Section, Aerospace Medical Research Laboratories, Wright-Patterson Air Force Base, Ohio. Aerospace Medicine. 34:145-149, February 1963.

B-4. Miller, N. D. Visual recovery from high intensity flashes. Annual Phase Report, USAF Contract AF 41(609)-2426, July 1965.

B-5. Vos, J. J., et al. Some reflections on the danger of and the protection against nuclear flashblindness and retinal burn. Report No. IZF 1964-25, Institute for Perception RVO-TNO, 1964. (DDC Cat. No. AD 456 728).

B-6. Vos, J. J. Temporary and permanent loss of visual functions by flashes at nuclear explosions. A theoretical approach. Report No. 1959-7, Institute for Perception RVO-TNO, 1959. (DDC Cat. No. AD 332 591), Confidential.

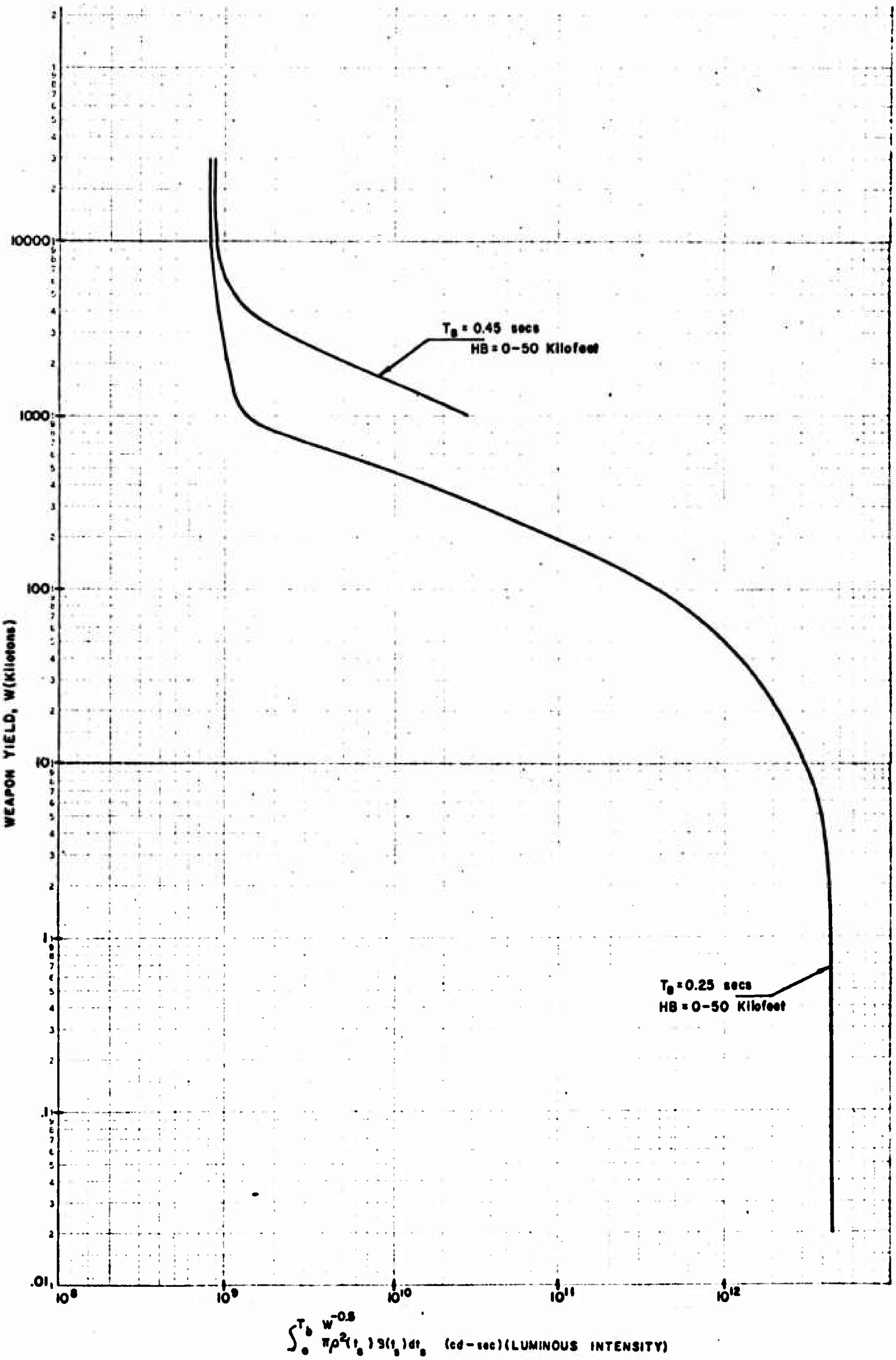

FIGURE B-1. Yield vs. luminous intensity

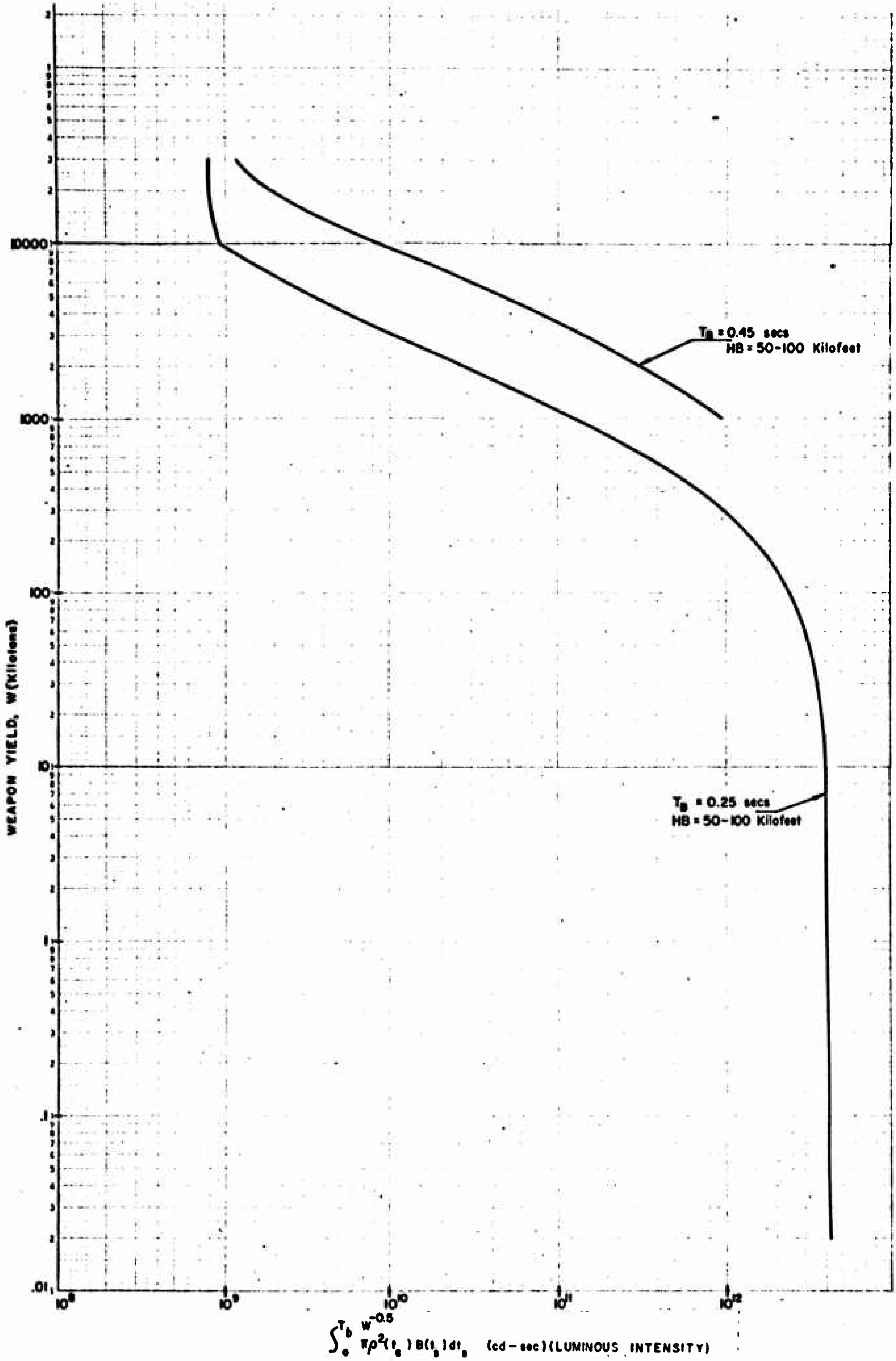

FIGURE B-2. Yield vs. luminous intensity

APPENDIX C

RETINAL BURN AND FLASHBLINDNESS COMPUTER PROGRAMS

APPENDIX C

RETINAL BURN AND FLASHBLINDNESS COMPUTER PROGRAMS

The major distinctions between the computer programs which determine retinal burn and flashblindness safe separation distances are (1) the formulation of the retinal exposure functions, and (2) the logic for choosing the safe separation distances based on these functions.

The formulation of the retinal exposure function, QREC, in the retinal burn program is based on direct image exposure and is not limited by image diameter. The flashblindness program bases safe separation distances on QREC or extra-image exposure, ETOT, and depends upon image diameter as set forth in Appendix B.

The basic structure of the burn and flashblindness programs is similar except for output format and the definition of safe separation solutions. Two subroutines appear in both programs; subroutine AIR computes relative temperature, pressure and density at any altitude up to 100 kilofeet, and subroutine TRANS, which uses subroutine AIR, computes the atmospheric transmission for a given slant path.

Retinal Burn Program

The retinal burn program is listed, except for system control cards, and card sequence numbers are referred to in the description which follows.

The atmospheric transmission subroutines are contained on cards MASS 001

to TRAN 009 and the input parameter symbolic names used in these subroutines are defined in the program symbol table.

The main, or calling, routine begins on card BURN 001 with format and specification statements. The program begins execution by reading an initial card containing various atmospheric and transmission constants. The next card read by the program at BURN 038 defines the problem situation in terms of weapon yield, fraction of the thermal energy given off before blink time, the detonation altitude, blink time, etc.

The program proceeds by determining the fireball diameter, DFB, and the retinal exposure near the fireball, QF. (Later, retinal exposure with a transmission coefficient, T, will be referred to as QREC.) The next step is to insure the existance of a safe separation envelope so that future iterations will be valid. This is accomplished by examination of the ratio, QRAT, the ratio of the safe allowable exposure to the safe received exposure on card BURN 064. If the ratio is less than 1.0 envelope coordinates are generated, otherwise the program comments accordingly and cycles to begin another situation.

The first step is generating an envelope is to establish the minimum envelope altitude, AMIN, and the maximum envelope altitude, AMAX. These two altitudes are determined in order to facilitate the selection of a satisfactory altitude interval, DELTA, with which to increment observer altitude from the lowest to the highest altitude on the envelope. This process assures that the envelope will be well defined by a sufficient number of solutions.

The determination of AMIN and AMAX is unique only because horizontal range does not apply. The selection of AMIN, AMAX, and DELTA is performed on cards BURN 070 through BURN 122.

Referring to both the program listing and the flowchart in Figure C-1, the mechanics of iterating toward a solution at each discreet observer altitude is illustrated.

The mechanics of iterating to a solution is comparable to the convergence of the Q_r and Q_r^T curves as explained in Appendix A. The procedure for obtaining these two curves is also outlined in Appendix A.

Flashblindness Program

The flashblindness logic is similar to the retinal burn logic until direct image and extra image exposures are calculated. These quantities are calculated at a distance from the fireball such that the image diameter is equal to one millimeter at that distance. From then on, the logic follows the path as illustrated in Figure C-2 and explained in detail in Appendix B. The envelopes generated are similar in appearance to retinal burn envelopes, but the safe separation distances for flashblindness are generally much greater.

PROGRAM SYMBOL TABLE

PROGRAM SYMBOL	SYMBOL USED BY	UNITS	DESCRIPTION
AK	both	$\frac{cm^2}{gm}$	Effective narrow beam extinction coefficient of air.
WK	both	$\frac{cm^2}{gm}$	Effective narrow beam extinction coefficient of water.
DWO	both	$\frac{gm}{cm^3}$	Sea level moisture content.
WL	burn	km	Moisture lapse rate.
WL	flash	kft^{-1}	Moisture lapse rate.
TX	both	pure	Transmission factors of all filters combined.
TE	both	pure	Transmission of the eye.
ABAR	both	pure	Thermal energy in visible region of the spectrum.
P	both	pure	Energy given off as thermal energy.
W	both	KT	Yield of weapon.
PERY	burn	pure	Energy given off within blink time.
HB	both	kft	Height of burst.
TB	both	sec	Blink time.
TS	both	sec	Time scaled.
F	both	pure	F stop of the eye.
FL	burn	cm	Focal length of the eye.
FQA	burn	pure	Safety factors applied to the allowed
FEA	flash	pure	retinal exposures.
FQR	burn	pure	Safety factors applied to the received
FER	flash	pure	retinal exposures.

PROGRAM SYMBOL	SYMBOL USED BY	UNITS	DESCRIPTION
EALLOW	flash	troland-sec	Allowable retinal exposure (Not safe sided).
PRIMEK	flash	I(cd-sec)	Luminous intensity.
ALPHA	flash	deg	Angular direction from center of the image to the point on the retina at which specified recovery time is desired.
PHB	both	pure	Pressure at burst height normalized to sea level.
THB	both	pure	Temperature at burst height normalized to sea level.
DHB	both	pure	Density at burst height normalized to sea level.
WSCL	both	pure	Relative yield as scaled by density at burst height.
TSF	both	pure	Scaled time.
FB(2, 11)	both	pure	Array containing relative fireball size behavior with respect to scaled time.
DFB	both	feet	Fireball diameter.
DFBM	both	cm	Fireball diameter.
A	both	feet	Altitude.
AMIN	both	feet	Altitude of bottom of safe separation envelope.
AMINI	both	feet	Altitude of bottom of safe separation envelope rounded off to nearest thousand feet.
AMAX	both	feet	Altitude of top of safe separation envelope.

PROGRAM SYMBOL	SYMBOL USED BY	UNITS	DESCRIPTION
AMAXI	both	feet	Altitude of top of safe separation envelope rounded off to nearest thousand feet.
DELTA	both	feet	The incremental altitude.
HR	both	feet	Horizontal range.
HRMILE	both	naut. mile	Horizontal range.
T	both	pure	Atmospheric transmission between burst and observer.
DIM	both	mm	Image diameter.
LAST	both	pure	Number of increments to go from AMINI to AMAXI.
ILAT	both	pure	Counts increments.
CRITD	flash	feet	Critical distance.
EMAX	flash		Intermediate result.
TERM	flash		Intermediate result.
ETOTA	flash		Intermediate result.
QRET	flash	troland-sec	Direct image retinal exposure (safe sided)
ETOT	flash	troland-sec	Extra-image retinal exposure. (safe sided)
DS	flash	feet	Slant range.
ABHR	flash		Intermediate result.
QF	burn	$\frac{cal}{cm^2}$	Retinal exposure not modified by transmission.

PROGRAM SYMBOL	SYMBOL USED BY	UNITS	DESCRIPTION
QREC	bcth	$\frac{cal}{cm^2}$	Retinal exposure (Not safe sided).
QA	burn	$\frac{cal}{cm^2}$	Allowable retinal exposure (Not safe sided).
QRAT	burn	pure	(QA*FQA)/(QREC*FQR).
DELTAHR	burn	feet	An increment used in the iteration.

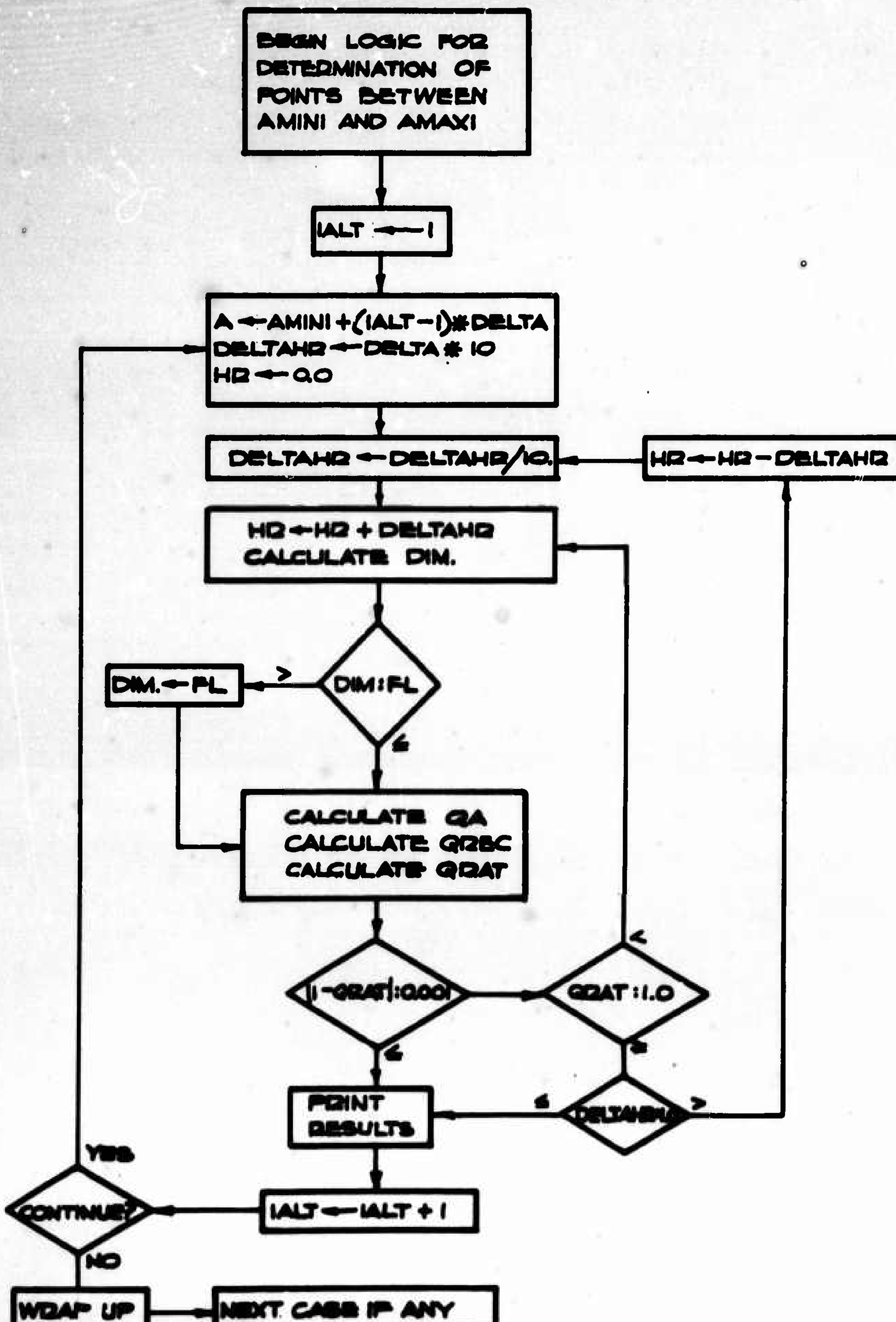

FIGURE C-1. Retinal burn flow diagram.

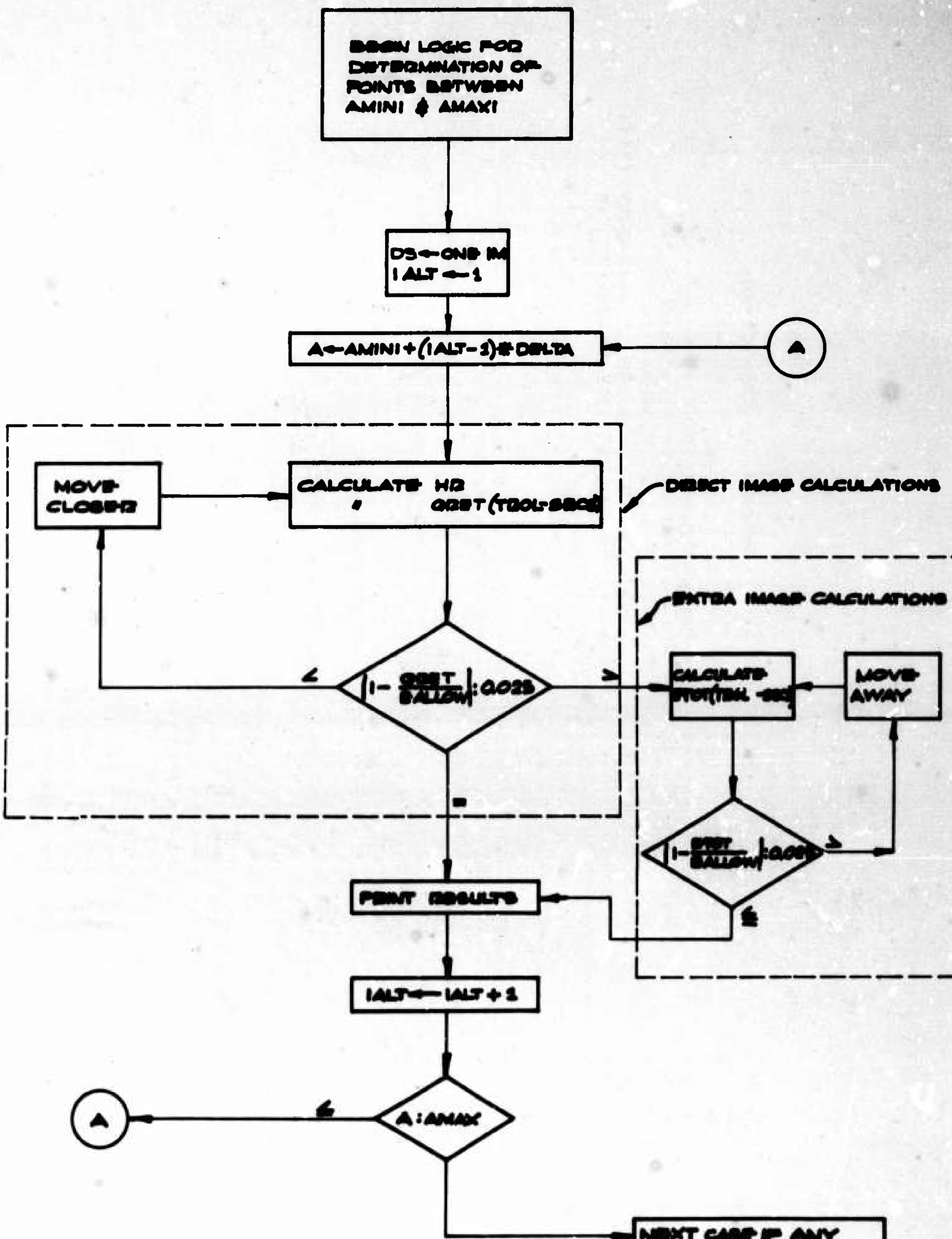

FIGURE C-2. Flashblindness flow diagram.

```
                JOB       ----------------
                DUMP      C,0,37777
                DUMP      A,1000,37777
                DUMP      F,1000,37777
                IBIT      44
          ABS   ALTAC     MAGTAPE,LIB
         I      EYE SAFE BURN
                SUBROUTINE RWMASS(AMRM,A1RM,A2RM,SRM,DRM,A0RM,GAMRM,
                WORM,WXRM,WMRM)$
                EQUIVALENCE (SP,BITS(1)),(DP,BITS(10)),
                (A3,SP(1)),(R1,SP(2)),(R2,SP(3)),(CM1,SP(4)),
                (D,SP(5)),(D1,SP(6)),(R0,SP(7)),(R02,SP(8)),(SG,SP(9)),
                (A3D,DP(1)),(R1D,DP(3)),(R2D,DP(5)),(CM1D,DP(7)),
                (DD,DP(9)),(D1D,DP(11)),(R0D,DP(13)),(R02D,DP(15)),(SGD,DP(17)),
                (A33D,DP(19)),(DDD,DP(21)),(R11D,DP(23)),(TD,DP(25))$
                COMMON BITS,SP,DP,A3,R1,R2,CM1,
                D,D1,R0,R02,SG,
                A3D,R1D,R2D,CM1D,
                DD,D1D,R0D,R02D,SGD,
                A33D,DDD,R11D,TD,
                S,A0,A1,A2,D2,ALF,GAM,AM,L,IG,W0,WX,WM$
                DIMENSION BITS(   35),SP(9),DP(26),
                A3D(2),R1D(2),R2D(2),CM1D(2),
                DD(2),D1D(2),R0D(2),R02D(2),SGD(2),
                A33D(2),DDD(2),R11D(2),TD(2)$
                TABLEDEF ONED(2),TWOD(2)$
                A1=A1RM'A2=A2RM'S=SRM'W0=WORM'WX=WXRM$
                IG=3'L=2$
                R1=RE+A1'R2=RE+A2'A3=A1-A2'ALF=S/RE$
                CALL COSM1(CM1,ALF)$
                CALL AMDP(SP   ,A3D ,0,4,1,1,1)$
                CALL AMDP(A3D  ,A3D ,3,A33D)$
                CALL AMDP(TWOD,R1D  ,3,TD   )$
                CALL AMDP(TD   ,R2D ,3,TD   )$
                CALL AMDP(TD   ,CM1D,3,TD   )$
                CALL AMDP(A33D,TD   ,2,DDD  )$
                CALL AMDP(DDD  ,DD  ,5      )$
                CALL AMDP(R1D  ,CM1D,3,TD   )$
                CALL AMDP(TD   ,A3D ,1,TD   )$
                CALL AMDP(TD   ,DD  ,4,SGD  )$
                CALL AMDP(R2D  ,R2D ,3,R11D)$
                CALL AMDP(SGD  ,SGD ,3,TD   )$
```

```
         CALL AMDP(ONED,TD  ,2,TD  )$
         CALL AMDP(R11D,TD  ,3,R02D)$
         CALL AMDP(R02D,R0D ,5     )$
         IF(A2)GTE(A1), GO TO A1M$
         CALL AMDP(R1D ,R1D ,3,R11D)$
A1M      CALL AMDP(R11D,R02D,2,TD  )$
         CALL AMDP(TD  ,D1D ,5     )$
         CALL AMDP(DD  ,SP  ,9,5,1,5)$
         A0=R0-RE'D2=D1-D'D2A=ABSF(D2)'AM=0.'WM=0.$
         GAM=57.2957795*ASINF(SG)$
         IF(D2)GT(-.0001),GO TO A3M$
         IF(A0)GT(0.0   ), GO TO A2M$
         IG=-3'AM=PINF'WM=PINF' GO TO X1M$
A2M      AM=2.*AMSIMP(SUM,0.,D2A,AXRHO)$
         IF(W0)E(0.),GO TO A3M$
         WM=2.*AMSIMP(SUM,0.,D2A,AWRHO)$
A3M      AM=AM+AMSIMP(SUM,D2A,D1,AXRHO)$
         IF(W0)E(0.),GO TO A5M$
         WM=WM+AMSIMP(SUM,D2A,D1,AWRHO)$
         WM=1E5*WM$
A5M      AM =.997391859E5*AM$
         AMRM=AM'DRM=D'A0RM=A0'GAMRM=GAM'WMRM=WM$
X1M      RETURN$
         STARTTAC$
CONED    O/2$
         D/1$
CTWOD    O/2$
         D/2$
CRE      F/6371.221$
CPINF    35/1T35'11/1T47$
 AXRHO   C/HLT,1'C/HLT,XRHO.XRHO$
 AWRHO   C/HLT,1'C/HLT,WRHO.WRHO$
C        SYMBOUT A0'A1'A2'A3'S'D'D1'D2'RE'R02'ALF'GAM'AM'L'IG'W0'WX'WM$
         REFOUT  XRHO.XRHO'WRHO.WRHO$
         ENDTAC  $
         END$
```

```
      SUBROUTINE XRHO(X) $
      EQUIVALENCE (SP,BITS(1)),(DP,BITS(10)),
      (A3,SP(1)),(R1,SP(2)),(R2,SP(3)),(CM1,SP(4)),
      (D,SP(5)),(D1,SP(6)),(R0,SP(7)),(R02,SP(8)),(SG,SP(9)),
      (A3D,DP(1)),(R1D,DP(3)),(R2D,DP(5)),(CM1D,DP(7)),
      (DD,DP(9)),(D1D,DP(11)),(R0D,DP(13)),(R02D,DP(15)),(SGD,DP(17)),
      (A33D,DP(19)),(DDD,DP(21)),(R11D,DP(23)),(TD,DP(25))$
      COMMON BITS,SP,DP,A3,R1,R2,CM1,
      D,D1,R0,R02,SG,
      A3D,R1D,R2D,CM1D,
      DD,D1D,R0D,R02D,SGD,
      A33D,DDD,R11D,TD,
      S,A0,A1,A2,D2,ALF,GAM,AM,L,IG$
      DIMENSION BITS(   35),SP(9),DP(26),
      A3D(2),R1D(2),R2D(2),CM1D(2),
      DD(2),D1D(2),R0D(2),R02D(2),SGD(2),
      A33D(2),DDD(2),R11D(2),TD(2)$
      TABLEDEF HL(22)$
      H=SQRTF(R02+X*X)-RE$
A6RHO IF(H)GTE(0.),GO TO A0RHO$
      IF(H)LTE(-.0005),GO TO X2RHO$
      H=0.$
A0RHO L=L-1'K=0$
A1RHO IF(H -HL(L))A2RHO,A5RHO,A4RHO $
A2RHO IF(K)X2RHO,A3RHO,A5RHO $
A3RHO L=L-1' IF(L)X2RHO,X2RHO,A1RHO$
A4RHO L=L+1'K=1'GO TO A1RHO $
A5RHO GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,
      22,23),L $
1     L=2$
2     X=1.225 E-3*(1.-2.2518827E-2* H        )** 4.2359' GO TO X1RHO $
3     X=3.6392E-4/EXPF(.15692      *(H-11.019))          ' GO TO X1RHO $
4     X=8.8035E-5/(1.+4.577983 E-3*(H-20.063))**35.167 ' GO TO X1RHO $
5     X=1.3225E-5/(1.+1.2098404E-2*(H-32.162))**13.201 ' GO TO X1RHO $
6     X=1.4275E-6/EXPF(.12426      *(H-47.35 ))          ' GO TO X1RHO $
7     X=7.5943E-7*(1.-7.258821 E-3*(H-52.429))**16.081 ' GO TO X1RHO $
8     X=2.5109E-7*(1.-1.5485454E-2*(H-61.591))** 7.5408' GO TO X1RHO $
9     X=2.001 E-8/EXPF(.18414      *(H-79.994))          ' GO TO X1RHO $
10    X=3.170 E-9/(1.+1.6606698E-2*(H-90.   ))**12.012 ' GO TO X1RHO $
11    X=4.974E-10/(1.+2.3736055E-2*(H-100.  ))** 7.612 ' GO TO X1RHO $
12    X=9.829E-11/(1.+3.8365624E-2*(H-110.  ))** 4.2955' GO TO X1RHO $
13    X=2.436E-11/(1.+5.5455428E-2*(H-120.  ))** 2.6389' GO TO X1RHO $
```

```
XRH 043  14     X=1.836E-12/(1.+1.5614428E-2*(H-150.  ))** 3.1713' GO TO X1RHO $
XRH 044  15     X=1.159E-12/(1.+9.003737 E-3*(H-160.  ))** 4.249 ' GO TO X1RHO $
XRH 045  16     X=8.036E-13/(1.+5.782018 E-3*(H-170.  ))** 5.6179' GO TO X1RHO $
XRH 046  17     X=4.347E-13/(1.+3.701921 E-3*(H-190.  ))** 7.4016' GO TO X1RHO $
XRH 047  18     X=1.564E-13/(1.+2.579563 E-3*(H-230.  ))** 8.8731' GO TO X1RHO $
XRH 048  19     X=3.585E-14/(1.+1.802638 E-3*(H-300.  ))**10.302 ' GO TO X1RHO $
XRH 049  20     X=6.498E-15/(1.+1.203342 E-3*(H-400.  ))**12.465 ' GO TO X1RHO $
XRH 050  21     X=1.577E-15/(1.+7.022907 E-4*(H-500.  ))**18.032 ' GO TO X1RHO $
XRH 051  22     X=4.640E-16/(1.+4.246039 E-4*(H-600.  ))**26.546 ' GO TO X1RHO $
XRH 052  23     GO TO 22 $
XRH 053  X1RHO  RETURN   $
XRH 054 TX2RHO  JMP      1SUBERR$
XRH 055         STARTTAC$
XRH 056 LHRHO   TJML     XRHO.XRHO-1$
XRH 057         TAM      H$
XRH 058         JMP      A6RHO$
XRH 059 CHL     F/0$
XRH 060         F/11.019$
XRH 061         F/20.063$
XRH 062         F/32.162$
XRH 063         F/47.35$
XRH 064         F/52.429$
XRH 065         F/61.591$
XRH 066         F/79.994$
XRH 067         F/90$
XRH 068         F/100$
XRH 069         F/110$
XRH 070         F/120$
XRH 071         F/150$
XRH 072         F/160$
XRH 073         F/170$
XRH 074         F/190$
XRH 075         F/230$
XRH 076         F/300$
XRH 077         F/400$
XRH 078         F/500$
XRH 079         F/600$
XRH 080         F/1E6$
XRH 081 C       SYMBOUT HL$
XRH 082         SYMBOUT HRHO.HRHO$
XRH 083         SAME     HRHO.HRHO.HRHO$
XRH 084         REFOUT   COMMON.RE$
XRH 085         ENDTAC   $
XRH 086         END$
```

```
WRH 001         SUBROUTINE WRHO(X) $
WRH 002         EQUIVALENCE (SP,BITS(1)),(DP,BITS(10)),
WRH 003         (A3,SP(1)),(R1,SP(2)),(R2,SP(3)),(CM1,SP(4)),
WRH 004         (D,SP(5)),(D1,SP(6)),(R0,SP(7)),(R02,SP(8)),(SG,SP(9)),
WRH 005         (A3D,DP(1)),(R1D,DP(3)),(R2D,DP(5)),(CM1D,DP(7)),
WRH 006         (DD,DP(9)),(D1D,DP(11)),(R0D,DP(13)),(R02D,DP(15)),(SGD,DP(17)),
WRH 007         (A33D,DP(19)),(DDD,DP(21)),(R11D,DP(23)),(TD,DP(25))$
WRH C08         COMMON BITS,SP,DP,A3,R1,R2,CM1,
WRH 009         D,D1,R0,R02,SG,
WRH 010         A3D,R1D,R2D,CM1D,
WRH 011         DD,D1D,R0D,R02D,SGD,
WRH 012         A33D,DDD,R11D,TD,
WRH 013         S,A0,A1,A2,D2,ALF,GAM,AM,L,IG,W0,WX,WM$
WRH 014         DIMENSION BITS(   35),SP(9),DP(26),
WRH 015         A3D(2),R1D(2),R2D(2),CM1D(2),
WRH 016         DD(2),D1D(2),R0D(2),R02D(2),SGD(2),
WRH 017         A33D(2),DDD(2),R11D(2),TD(2)$
WRH 018         H=SQRTF(R02+X*X)-RE$
WRH 019         IF(H)GTE(0.),GO TO A0WRHO$
WRH 020         IF(H)LTE(-.0005),GO TO X2WRHO$
WRH 021         H=0.$
WRH 022  A0WRHO X=W0/EXPF( WX*H)$
WRH 023  X1WRHO RETURN   $
WRH 024 TX2WRHO JMP      1SUBERR$
WRH 025 T       REFOUT   COMMON.RE$
WRH 026         ENDS
```

```
COS 001          STARTTAC $
COS 002          NAME     COSM1$
COS 003          SYMBOUT  COSM1.COSM1$
COS 004 LCOSM1   TJM      X$
COS 005          TQM      A$
COS 006          TDM      A2$
COS 007          FMMRS    A2$
COS 008          TMD      F/1$
COS 009          TDM      P$
COS 010          TMD      F/0$
COS 011          TDM      C$
COS 012          TMD      F/2$
COS 013          TDM      D$
COS 014          TDM      E$
COS 015          TDM      F$
COS 016          TMD      1/1T19$
COS 017          DORMS    J$
COS 018          JMP      I$
COS 019   H      TMA      F/1$
COS 020          FAMS     E$
COS 021          TDQ      $
COS 022          FMMRS    F$
COS 023          TMA      F/1$
COS 024          FAMS     E$
COS 025          TDQ      $
COS 026          FMMRS    F$
COS 027   I      TMQ      A2$
COS 028          FMMRS    P$
COS 029          FDA      F$
COS 030          TQM      B$
COS 031          NOP      $
COS 032 LJ       FCSM     B$
COS 033          FAMS     C$
COS 034          TMD      D$
COS 035          JAED     K$
COS 036          TAM      D$
COS 037          TMA      1/1T19$
COS 038          AWCS     J$
COS 039          JMP      H$
COS 040   K      TMA      F/0$
COS 041          TMQ      C$
COS 042          JAGQF    X-1$
```

```
COS 043             JMP     1SUBERR$
COS 044             TDA     $
COS 045             TMQ     A$
COS 046   X         JMP     (P)$
COS 047   A         $
COS 048   A2        $
COS 049   B         $
COS 050   C         $
COS 051   D         $
COS 052   E         $
COS 053   F         $
COS 054   P         $
COS 055             ENDSUB  $
COS 056             END     $
COS 057             ENDTAC $
```

```
      SUBROUTINE AIR(H,P,T,DA) $
      HKM=H*3.048E-4 $
      IF(HKM) GT (25.),GO TO 20 $
      IF(HKM) GT (11.),GO TO 10 $
      T=288.16-6.5*HKM $
      P=1033.2*(T/288.16)**5.2561 $
      DA=1.225E-3*(T/288.16)**4.2561 $
      GO TO 30 $
10    T=216.66 $
      C=EXPF(0.15769*(11.-HKM)) $
      P=C*231.47 $
      DA=C*3.648E-4 $
      GO TO 30 $
20    T=216.66+3.*(HKM-25.) $
      P=25.772*(216.66/T)**11.3882 $
      DA=4.0639E-5*(216.66/T)**12.3882 $
30    T=T/288.16 $
      P=P/1033.2 $
      DA=DA/1.225E-3 $
      RETURN $
      END $
```

```
TRAN001          SUBROUTINE TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
TRAN002          HBKM=HB*3.048E-4 $
TRAN003          AKM=A*3.048E-4 $
TRAN004          HRKM=HR*3.048E-4 $
TRAN005          IF(HRKM) E (C.0),HRKM=3.048E-4 $
TRAN006          CALL RWMASS(AM,HBKM,AKM,HRKM,SR,AO,GAM,DWO,WL,WM) $
TRAN007   10     T=EXPF(-AK*AM-WK*WM) $
TRAN008          RETURN $
TRAN009          END $
```

```
1000    FORMAT(8F10.0) $
1200    FORMAT(7F10.0,2F5.0) $
1300    FORMAT(1H1) $
1400    FORMAT(/////////////42X,35HNO RETINAL BURN ENVELOPE EXISTS FOR/
                42X,16HTHIS SITUATION -//
                42X,16HYIELD          = ,1PE11.4/
                42X,16HBURST HEIGHT   = ,E11.4/
                42X,16HPERCENT YIELD  = ,E11.4/
                42X,16HBLINK TIME     = ,E11.4,7H DURING,A7,7HMISSION/
                42X,16HQA FACTOR      = ,E11.4/
                42X,16HQR FACTOR      = ,E11.4) $
150C    FORMAT(/40X,7HW     = 1PE11.4,4X,7HAK    = E11.4/
                 40X,7HHB    = E11.4,4X,7HWK    = E11.4/
                 40X,7HDFB   = E11.4,4X,7HDWO   = E11.4/
                 4CX,7HPERY  = E11.4,4X,7HWL    = E11.4/
                 40X,7HTB    = E11.4,4X,7HTX    = E11.4/
                 40X,7HTS    = E11.4,4X,7HTE    = E11.4/
                 40X,7HTSF   = E11.4,4X,7HABAR  = E11.4/
                 40X,7HF     = E11.4,4X,7HP     = E11.4/
                 40X,7HFL    = E11.4,4X,7HFQA   = E11.4/
                                   62X,7HFQR   = E11.4) $
1600    FORMAT(35X,33HCONDITION AT MINIMUM ALTITUDE OF 1PE11.4,5H FEET/
                61X,7HQA    = E11.4/
                61X,7HQREC = E11.4/
                61X,7HDIM1 = E11.4) $
1700    FORMAT(35X,33HCONDITION AT MAXIMUM ALTITUDE OF 1PE11.4,5H FEET/
                61X,7HQA    = E11.4/
                61X,7HQREC = E11.4/
                61X,7HDIM2 = E11.4) $
1800    FORMAT(/35X,21HLET DELTA ALTITUDE = 1PE11.4,5H FEET/////19X,
        75HALTITUDE     H RANGE      H RANGE      Q ALLOWABLE  Q RECEIVE
        D   IMAGE DIAM/21X,4HFEET,7X,6HN MILE,9X,3H FT,37X,2HMM) $
1900    FORMAT(18X,1PE11.4,2X,5(E11.4,2X)) $
        TABLEDEF FB(2,11) $
T       TMD      F/1.E-2$
T       TDM      AMSIMP.AMSIMP+3$
        READ 1000,AK,WK,DWO,WL,TX,TE,ABAR,P $
CARD    READ 1200,W,PERY,HB,TB,TS,F,FL,FQA,FQR $
        IF(W) E (0.0),GO TO EXIT $
        PRINT 1300 $
        CALL AIR(HB,PHB,THB,DHB) $
        WSCL=0.032*(DHB*W)**0.5 $
```

```
BURN043          IF(TB) E (0.0),TB=(TS-0.0025)*WSCL'GO TO 10 $
BURN044          IF(TS) E (0.0),TS=0.0025+TB/WSCL'GO TO 10 $
BURN045          IF(TB) GT ((TS-.0025)*WSCL),TB=(TS-.0025)*WSCL'GO TO 10 $
BURN046          TS=.0025+TB/WSCL $
BURN047   10     TSF=.032*TS $
BURN048          IF(TS) GTE (FB(1,11)),DF=FB(2,11)'GO TO 40 $
BURN049          IF(TS) LT (FB(1,1)),I=2'GO TO 30 $
BURN050          DO 20 I=2,11 $
BURN051          IF(TS) LT (FB(1,I)),GO TO 30 $
BURN052   20     CONTINUE $
BURN053   30     DF=FB(2,I-1)+LOGF(TS/FB(1,I-1))*(FB(2,I)-FB(2,I-1))/
BURN054                                     LOGF(FB(1,I)/FB(1,I-1)) $
BURN055   40     DFB=360.0*DF $
BURN056          DFB=DFB*W**0.4*(1./DHB)**0.333 $
BURN057          DFBM=30.48*DFB $                          DIAMETER IN CM
BURN058          QF=7.95775E10*ABAR*P*PERY*W*TE*TX/(F*F*DFBM*DFBM) $
BURN059          HR=1.0 $
BURN060          A=HB-1.0 $                        CHECK TO INSURE THAT AN INTER-
BURN061          T=1.0 $                           SECTION DOES EXIST
BURN062          QREC=QF*T $
BURN063          QA=10.**(.192*LOG10F((TB*1000.)**1.605)-.766) $
BURN064          QRAT=(FQA*QA)/(FQR*QREC) $
BURN065          IF(QRAT) LT (1.0),GO TO TOWN $
BURN066          IF(F) GT (5.0),TITLE(1)=DAY $
BURN067          IF(F) LT (5.0),TITLE(1)=NIGHT $
BURN068          PRINT 1400,W,HB,PERY,TB,TITLE(1),FQA,FQR $
BURN069          GO TO CARD $
BURN070   TOWN   HR=0.0'QA=0.0'QREC=0.0'DIM=0.0 $
BURN071          PRINT 1500,W,AK,HB,WK,DFB,DWO,PERY,WL,TB,TX,TS,TE,TSF,ABAR,F,P,
BURN072          FL,FQA,FQR $
BURN073          A=0.0 $
BURN074          IF(HB) LTE (1000.),AMIN=0.0'GO TO 80 $
BURN075          A=HB'DELTA=10000. $               DETERMINE ALTITUDE OF BOTTOM
BURN076   50     DELTA=DELTA/10. $
BURN077   60     A=A-DELTA $
BURN078          IF(A) LTE (0.0),AMIN=0.0'GO TO 80 $    ARE WE AT SEA LEVEL
BURN079          DIM=FL*DFB/(HB-A) $
BURN080          IF(DIM) GT (FL),DIM=FL $
BURN081          QA=10.**((.044/(DIM+.02)+.19)*LOG10F((TB*1000.)**
BURN082             (-.079/(DIM+.12)+1.61))+.06/DIM -.77) $
BURN083          CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
BURN084          QREC=QF*T $
```

```
BURN085          QRAT=(FQA*QA)/(FQR*QREC) $
BURN086          IF(ABSF(1.-QRAT)) LTE (.001),GO TO 70 $      HAVE WE CONVERGED
BURN087          IF(QRAT) LT (1.0),GO TO 60 $                 ARE WE INSIDE
BURN088          IF(DELTA) LTE (.01*A),GO TO 70 $             ARE WE WITHIN 1 PCT
BURN089          A=A+DELTA $
BURN090          GO TO 50 $
BURN091    70    AMIN=A $
BURN092    80    PRINT 1600,A,QA,QREC,DIM $
BURN093          A=HB'DELTA=100000. $              DETERMINE ALTITUDE OF TOP
BURN094    90    DELTA=DELTA/10. $
BURN095   100    A=A+DELTA $
BURN096          IF(A) GTE (100000.),A=100000. $              CHECK MODEL LIMIT
BURN097          IF(A-HB) E (0.0),GO TO 110 $
BURN098          DIM=FL*DFB/(A-HB) $
BURN099          IF(DIM) GT (FL),DIM=FL $
BURN100          QA=10.**((.044/(DIM+.02)+.19)*LOG10F((TB*1000.)**
BURN101             (-.079/(DIM+.12)+1.61))+.06/DIM -.77) $
BURN102          CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
BURN103          QREC=QF*T $
BURN104          QRAT=(FQA*QA)/(FQR*QREC) $
BURN105          IF(A) E (100000.),GO TO 110 $                CHECK MODEL LIMIT
BURN106          IF(ABSF(1.-QRAT)) LTE (.001),GO TO 110 $     HAVE WE CONVERGED
BURN107          IF(QRAT) LT (1.0),GO TO 100 $                ARE WE INSIDE
BURN108          IF(DELTA) LTE (.01*A),GO TO 110 $            ARE WE WITHIN 1 PCT
BURN109          A=A-DELTA $
BURN110          GO TO 90 $
BURN111   110    AMAX=A $
BURN112          PRINT 1700,AMAX,QA,QREC,DIM $
BURN113          AMAXI=1000.*INTF(AMAX/1000.) $
BURN114          AMINI=1000.*INTF((AMIN+999.)/1000.) $
BURN115          IF(AMAXI-AMINI) GT (40000.),DELTA=5000.'GO TO 120 $   SET UP A
BURN116          IF(AMAXI-AMINI) GT (20000.),DELTA=2000.'GO TO 120 $   DELTA ALT
BURN117          IF(AMAXI-AMINI) GT (10000.),DELTA=1000.'GO TO 120 $  FROM MIN TO
BURN118          IF(AMAXI-AMINI) GT ( 4000.),DELTA= 500.'GO TO 120 $   MAX ALT
BURN119          IF(AMAXI-AMINI) GT ( 2000.),DELTA= 200.'GO TO 120 $
BURN120          DELTA=100. $
BURN121   120    AMINI=INTF(AMINI/DELTA)*DELTA $  BOTTOM ALTITUDE TO NEAREST KFT
BURN122          LAST=(AMAXI-AMINI)/DELTA+1.0 $    NUMBER DELTA ALTS TO REACH TOP
BURN123          PRINT 1800,DELTA $
BURN124          HR=0.0 $
BURN125          DO 160 IALT=1,LAST $
BURN126          A=AMINI+(IALT-1)*DELTA'DELTAHR=DELTA*10. $
```

```
 130    DELTAHR=DELTAHR/10. $
 140    HR=HR+DELTAHR $
        DIM=FL*DFB/SQRTF((A-HB)**2+HR**2) $
        IF(DIM) GT (FL),DIM=FL $
        QA=10.**((.044/(DIM+.02)+.19)*LOG10F((TB*1000.)**
           (-.079/(DIM+.12)+1.61))+.06/DIM -.77) $
        CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
        QREC=QF*T $
        QRAT=(FQA*QA)/(FQR*QREC) $
        IF(ABSF(1.-QRAT)) LTE (.001),GO TO 150 $     HAVE WE CONVERGED
        IF(QRAT) LT (1.0),GO TO 140 $                ARE WE INSIDE
        IF(DELTAHR) LTE (.01*HR),GO TO 150 $         ARE WE WITHIN 1 PCT
        HR=HR-DELTAHR $
        GO TO 130 $
 150    HRMILE=HR/6080. $
        PRINT 1900,A,HRMILE,HR,QA,QREC,DIM $
 160    CONTINUE $
        GO TO CARD $
 EXIT   STOP $
TFB     F/.001$
T       F/.1$
T       F/.002$
T       F/.135$
T       F/.0045$
T       F/.19$
T       F/.01$
T       F/.265$
T       F/.02$
T       F/.345$
T       F/.05$
T       F/.4675$
T       F/.15$
T       F/.65$
T       F/1.0$
T       F/1.0$
T       F/2.0$
T       F/1.09$
T       F/4.0$
T       F/1.165$
T       F/8.0$
T       F/1.2$
TDAY    W/  DAY   $
TNIGHT  W/  NIGHT $
        END $
        ABS     2,EYE SAFE BURN,GO
```

```
                 JOB       ----------------
                 DUMP      C,0,37777
                 DUMP      A,1000,37777
                 DUMP      F,1000,37777
                 IBIT      44
            ABS  ALTAC     MAGTAPE,LIB
           I     EYE SAFE FLASH
                 SUBROUTINE RWMASS(AMRM,A1RM,A2RM,SRM,DRM,AORM,GAMRM,
                 WORM,WXRM,WMRM)$
                 EQUIVALENCE (SP,BITS(1)),(DP,BITS(10)),
                 (A3,SP(1)),(R1,SP(2)),(R2,SP(3)),(CM1,SP(4)),
                 (D,SP(5)),(D1,SP(6)),(RO,SP(7)),(RO2,SP(8)),(SG,SP(9)),
                 (A3D,DP(1)),(R1D,DP(3)),(R2D,DP(5)),(CM1D,DP(7)),
                 (DD,DP(9)),(D1D,DP(11)),(ROD,DP(13)),(RO2D,DP(15)),(SGD,DP(17)),
                 (A33D,DP(19)),(DDD,DP(21)),(R11D,DP(23)),(TD,DP(25))$
                 COMMON BITS,SP,DP,A3,R1,R2,CM1,
                 D,D1,RO,RO2,SG,
                 A3D,R1D,R2D,CM1D,
                 DD,D1D,ROD,RO2D,SGD,
                 A33D,DDD,R11D,TD,
                 S,AO,A1,A2,D2,ALF,GAM,AM,L,IG,WO,WX,WM$
                 DIMENSION BITS(  35),SP(9),DP(26),
                 A3D(2),R1D(2),R2D(2),CM1D(2),
                 DD(2),D1D(2),ROD(2),RO2D(2),SGD(2),
                 A33D(2),DDD(2),R11D(2),TD(2)$
                 TABLEDEF ONED(2),TWOD(2)$
                 A1=A1RM'A2=A2RM'S=SRM'WO=WORM'WX=WXRM$
                 IG=3'L=2$
                 R1=RE+A1'R2=RE+A2'A3=A1-A2'ALF=S/RE$
                 CALL COSM1(CM1,ALF)$
                 CALL AMDP(SP   ,A3D  ,0,4,1,1,1)$
                 CALL AMDP(A3D  ,A3D  ,3,A33D)$
                 CALL AMDP(TWOD,R1D  ,3,TD   )$
                 CALL AMDP(TD   ,R2D  ,3,TD   )$
                 CALL AMDP(TD   ,CM1D,3,TD   )$
                 CALL AMDP(A33D,TD   ,2,DDD  )$
                 CALL AMDP(DDD  ,DD   ,5      )$
                 CALL AMDP(R1D  ,CM1D,3,TD   )$
                 CALL AMDP(TD   ,A3D  ,1,TD   )$
                 CALL AMDP(TD   ,DD   ,4,SGD  )$
                 CALL AMDP(R2D  ,R2D  ,3,R11D)$
                 CALL AMDP(SGD  ,SGD  ,3,TD   )$
```

```
RWM 036          CALL AMDP(ONED,TD   ,2,TD   )$
RWM 037          CALL AMDP(R11D,TD   ,3,R02D)$
RWM 038          CALL AMDP(R02D,ROD ,5       )$
RWM 039          IF(A2)GTE(A1), GO TO A1M$
RWM 040          CALL AMDP(R1D ,R1D ,3,R11D)$
RWM 041   A1M    CALL AMDP(R11D,R02D,2,TD   )$
RWM 042          CALL AMDP(TD   ,D1D ,5      )$
RWM 043          CALL AMDP(DD   ,SP   ,9,5,1,5)$
RWM 044          A0=R0-RE'D2=D1-D'D2A=ABSF(D2)'AM=0.'WM=0.$
RWM 045          GAM=57.2957795*ASINF(SG)$
RWM 046          IF(D2)GT(-.0001),GO TO A3M$
RWM 047          IF(A0)GT(0.0    ), GO TO A2M$
RWM 048          IG=-3'AM=PINF'WM=PINF' GO TO X1M$
RWM 049   A2M    AM=2.*AMSIMP(SUM,0.,D2A,AXRHO)$
RWM 050          IF(W0)E(0.),GO TO A3M$
RWM 051          WM=2.*AMSIMP(SUM,0.,D2A,AWRHO)$
RWM 052   A3M    AM=AM+AMSIMP(SUM,D2A,D1,AXRHO)$
RWM 053          IF(W0)E(0.),GO TO A5M$
RWM 054          WM=WM+AMSIMP(SUM,D2A,D1,AWRHO)$
RWM 055          WM=1E5*WM$
RWM 056   A5M    AM =.997391859E5*AM$
RWM 057          AMRM=AM'DRM=D'A0RM=A0'GAMRM=GAM'WMRM=WM$
RWM 058   X1M    RETURN$
RWM 059          STARTTAC$
RWM 060 CONED    O/2$
RWM 061          D/1$
RWM 062 CTWOD    O/2$
RWM 063          D/2$
RWM 064 CRE      F/6371.221$
RWM 065 CPINF    35/1T35'11/1T47$
RWM 066  AXRHO   C/HLT,1'C/HLT,XRHO.XRHO$
RWM 067  AWRHO   C/HLT,1'C/HLT,WRHO.WRHO$
RWM 068 C        SYMBOUT A0'A1'A2'A3'S'D'D1'D2'RE'R02'ALF'GAM'AM'L'IG'W0'WX'WM$
RWM 069          REFOUT  XRHO.XRHO'WRHO.WRHO$
RWM 070          ENDTAC  $
RWM 071          END$
```

```
          SUBROUTINE XRHO(X) $
          EQUIVALENCE (SP,BITS(1)),(DP,BITS(10)),
          (A3,SP(1)),(R1,SP(2)),(R2,SP(3)),(CM1,SP(4)),
          (D,SP(5)),(D1,SP(6)),(R0,SP(7)),(R02,SP(8)),(SG,SP(9)),
          (A3D,DP(1)),(R1D,DP(3)),(R2D,DP(5)),(CM1D,DP(7)),
          (DD,DP(9)),(D1D,DP(11)),(R0D,DP(13)),(R02D,DP(15)),(SGD,DP(17)),
          (A33D,DP(19)),(DDD,DP(21)),(R11D,DP(23)),(TD,DP(25))$
          COMMON BITS,SP,DP,A3,R1,R2,CM1,
          D,D1,R0,R02,SG,
          A3D,R1D,R2D,CM1D,
          DD,D1D,R0D,R02D,SGD,
          A33D,DDD,R11D,TD,
          S,A0,A1,A2,D2,ALF,GAM,AM,L,IG$
          DIMENSION BITS(  35),SP(9),DP(26),
          A3D(2),R1D(2),R2D(2),CM1D(2),
          DD(2),D1D(2),R0D(2),R02D(2),SGD(2),
          A33D(2),DDD(2),R11D(2),TD(2)$
          TABLEDEF HL(22)$
          H=SQRTF(R02+X*X)-RE$
A6RHO     IF(H)GTE(0.),GO TO A0RHO$
          IF(H)LTE(-.0005),GO TO X2RHO$
          H=0.$
A0RHO     L=L-1'K=0$
A1RHO     IF(H -HL(L))A2RHO,A5RHO,A4RHO $
A2RHO     IF(K)X2RHO,A3RHO,A5RHC $
A3RHO     L=L-1' IF(L)X2RHO,X2RHO,A1RHO$
A4RHO     L=L+1'K=1'GO TO A1RHO $
A5RHO     GO TO (1,2,3,4,5,6,7,8,9,10,11,12,13,14,15,16,17,18,19,20,21,
          22,23),L $
1         L=2$
2         X=1.225 E-3*(1.-2.2518827E-2* H         )** 4.2559' GO TO X1RHO $
3         X=3.6392E-4/EXPF(.15692      *(H-11.019))         ' GO TO X1RHO $
4         X=8.8035E-5/(1.+4.577983 E-3*(H-20.063))**35.167 ' GO TO X1RHO $
5         X=1.3225E-5/(1.+1.2098404E-2*(H-32.162))**13.201 ' GO TO X1RHO $
6         X=1.4275E-6/EXPF(.12426      *(H-47.35 ))         ' GO TO X1RHO $
7         X=7.5943E-7*(1.-7.258821 E-3*(H-52.429))**16.081 ' GO TO X1RHO $
8         X=2.5109E-7*(1.-1.5485454E-2*(H-61.591))** 7.5408' GO TO X1RHO $
9         X=2.001 E-8/EXPF(.18414      *(H-79.994))         ' GO TO X1RHO $
10        X=3.170 E-9/(1.+1.6606698E-2*(H-90.    ))**12.012 ' GO TO X1RHO $
11        X=4.974E-10/(1.+2.3736055E-2*(H-100.   ))** 7.612 ' GO TC X1RHO $
12        X=9.829E-11/(1.+3.8365624E-2*(H-110.   ))** 4.2955' GC TO X1RHC $
13        X=2.436E-11/(1.+5.5455428E-2*(H-120.   ))** 2.6389' GC TO X1RHO $
14        X=1.836E-12/(1.+1.5614428E-2*(H-150.   ))** 3.1713' GO TC X1RHO $
```

```
XRH 044  15      X=1.159E-12/(1.+9.003737 E-3*(H-160.  ))** 4.249 ' GO TO X1RHO $
XRH 045  16      X=8.036E-13/(1.+5.782018 E-3*(H-170.  ))** 5.6179' GO TO X1RHO $
XRH 046  17      X=4.347E-13/(1.+3.701921 E-3*(H-190.  ))** 7.4016' GO TO X1RHO $
XRH 047  18      X=1.564E-13/(1.+2.579563 E-3*(H-230.  ))** 8.8731' GO TO X1RHO $
XRH 048  19      X=3.585E-14/(1.+1.802638 E-3*(H-300.  ))**10.302 ' GO TO X1RHO $
XRH 049  20      X=6.498E-15/(1.+1.203342 E-3*(H-400.  ))**12.465 ' GO TO X1RHO $
XRH 050  21      X=1.577E-15/(1.+7.022907 E-4*(H-500.  ))**18.032 ' GO TO X1RHO $
XRH 051  22      X=4.640E-16/(1.+4.246039 E-4*(H-600.  ))**26.546 ' GO TO X1RHO $
XRH 052  23      GO TO 22 $
XRH 053  X1RHO   RETURN  $
XRH 054 TX2RHO   JMP      1SUBERR$
XRH 055          STARTTAC$
XRH 056 LHRHO    TJML     XRHO.XRHO-1$
XRH 057          TAM      H$
XRH 058          JMP      A6RHO$
XRH 059 CHL      F/0$
XRH 060          F/11.019$
XRH 061          F/20.063$
XRH 062          F/32.162$
XRH 063          F/47.35$
XRH 064          F/52.429$
XRH 065          F/61.591$
XRH 066          F/79.994$
XRH 067          F/90$
XRH 068          F/100$
XRH 069          F/110$
XRH 070          F/120$
XRH 071          F/150$
XRH 072          F/160$
XRH 073          F/170$
XRH 074          F/190$
XRH 075          F/230$
XRH 076          F/300$
XRH 077          F/400$
XRH 078          F/500$
XRH 079          F/600$
XRH 080          F/1E6$
XRH 081 C        SYMBOUT HL$
XRH 082          SYMBOUT HRHO.HRHO$
XRH 083          SAME     HRHO.HRHO,HRHO$
XRH 084          REFOUT   COMMON.RE$
XRH 085          ENDTAC   $
XRH 086          END$
```

```
        SUBROUTINE WRHO(X) $
        EQUIVALENCE (SP,BITS(1)),(DP,BITS(10)),
        (A3,SP(1)),(R1,SP(2)),(R2,SP(3)),(CM1,SP(4)),
        (D,SP(5)),(D1,SP(6)),(R0,SP(7)),(R02,SP(8)),(SG,SP(9)),
        (A3D,DP(1)),(R1D,DP(3)),(R2D,DP(5)),(CM1D,DP(7)),
        (DD,DP(9)),(D1D,DP(11)),(R0D,DP(13)),(R02D,DP(15)),(SGD,DP(17)),
        (A33D,DP(19)),(DDD,DP(21)),(R11D,DP(23)),(TD,DP(25))$
        COMMON BITS,SP,DP,A3,R1,R2,CM1,
        D,D1,R0,R02,SG,
        A3D,R1D,R2D,CM1D,
        DD,D1D,R0D,R02D,SGD,
        A33D,DDD,R11D,TD,
        S,A0,A1,A2,D2,ALF,GAM,AM,L,IG,W0,WX,WM$
        DIMENSION BITS(   35),SP(9),DP(26),
        A3D(2),R1D(2),R2D(2),CM1D(2),
        DD(2),D1D(2),R0D(2),R02D(2),SGD(2),
        A33D(2),DDD(2),R11D(2),TD(2)$
        H=SQRTF(R02+X*X)-RE$
        IF(H)GTE(0.),GO TO A0WRHO$
        IF(H)LTE(-.0005),GO TO X2WRHO$
        H=0.$
 A0WRHO X=W0/EXPF( WX*H)$
 X1WRHO RETURN  $
TX2WRHO JMP     1SUBERR$
T       REFOUT  COMMON.RE$
        END$
```

```
COS 001          STARTTAC $
COS 002          NAME     COSM1$
COS 003          SYMBOUT  COSM1.COSM1$
COS 004 LCOSM1   TJM      X$
COS 005          TQM      A$
COS 006          TDM      A2$
COS 007          FMMRS    A2$
COS 008          TMD      F/1$
COS 009          TDM      P$
COS 010          TMD      F/0$
COS 011          TDM      C$
COS 012          TMD      F/2$
COS 013          TDM      D$
COS 014          TDM      E$
COS 015          TDM      F$
COS 016          TMD      1/1T19$
COS 017          DORMS    J$
COS 018          JMP      I$
COS 019  H       TMA      F/1$
COS 020          FAMS     E$
COS 021          TDQ      $
COS 022          FMMRS    F$
COS 023          TMA      F/1$
COS 024          FAMS     E$
COS 025          TDQ      $
COS 026          FMMRS    F$
COS 027  I       TMQ      A2$
COS 028          FMMRS    P$
COS 029          FDA      F$
COS 030          TQM      B$
COS 031          NOP      $
COS 032 LJ       FCSM     B$
COS 033          FAMS     C$
COS 034          TMD      D$
COS 035          JAED     K$
COS 036          TAM      D$
COS 037          TMA      1/1T19$
COS 038          AWCS     J$
COS 039          JMP      H$
COS 040  K       TMA      F/0$
COS 041          TMQ      C$
COS 042          JAGQF    X-1$
```

```
COS 043           JMP      1SUBERR$
COS 044           TDA      $
COS 045           TMQ      A$
COS 046   X       JMP      (P)$
COS 047   A       $
COS 048   A2      $
COS 049   B       $
COS 050   C       $
COS 051   D       $
COS 052   E       $
COS 053   F       $
COS 054   P       $
COS 055           ENDSUB   $
COS 056           END      $
COS 057           ENDTAC $
```

```
      SUBROUTINE AIR(H,P,T,DA) $
      HKM=H*3.048E-4 $
      IF(HKM) GT (25.),GO TO 20 $
      IF(HKM) GT (11.),GO TO 10 $
      T=288.16-6.5*HKM $
      P=1033.2*(T/288.16)**5.2561 $
      DA=1.225E-3*(T/288.16)**4.2561 $
      GO TO 30 $
10    T=216.66 $
      C=EXPF(0.15769*(11.-HKM)) $
      P=C*231.47 $
      DA=C*3.648E-4 $
      GO TO 30 $
20    T=216.66+3.*(HKM-25.) $
      P=25.772*(216.66/T)**11.3882 $
      DA=4.0639E-5*(216.66/T)**12.3882 $
30    T=T/288.16 $
      P=P/1033.2 $
      DA=DA/1.225E-3 $
      RETURN $
      END $
```

```
TRN 001          SUBROUTINE TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
TRN 002          HBKM=HB*3.048E-4 $
TRN 003          AKM=A*3.048E-4 $
TRN 004          HRKM=HR*3.048E-4 $
TRN 005          IF(HRKM) E (0.0),HRKM=3.048E-4 $
TRN 006          CALL RWMASS(AM,HBKM,AKM,HRKM,SR,AO,GAM,DWO,WL,WM) $
TRN 007          IF(AO)LTE(0.0),GO TO 20 $        CHECK EARTH INTERSECTION
TRN 008   10     T=EXPF(-AK*AM-WK*WM) $
TRN 009   20     RETURN $
TRN 010          END $
```

```
1000   FORMAT(8F10.0) $
1100   FORMAT(3A8,7X,I1,11X,F6.0,9X,F5.0) $
1200   FORMAT(2F8.0,2E8.0,4F5.0,2F9.0,2F5.0) $
1300   FORMAT(1H1) $
1400   FORMAT(////////////42X,37HNO FLASHBLINDNESS ENVELOPE EXISTS FOR/
               42X,16HTHIS SITUATION -//
               42X,16HYIELD          = ,1PE11.4/
               42X,16HBURST HEIGHT   = ,E11.4/
               42X,16HPERCENT YIELD = ,E11.4/
               42X,16HBLINK TIME     = ,E11.4,7H DURING,A7,7HMISSION/
               42X,16HEA FACTOR      = ,E11.4/
               42X,16HER FACTOR      = ,E11.4) $
1500   FORMAT(/40X,7HW     = 1PE11.4,4X,7HAK    = E11.4,5X,5HFLASH,
               /40X,7HHB    = ,E11.4,4X,7HWK    = ,E11.4,5X,9HBLINDNESS,
               /40X,7HDFB   = ,E11.4,4X,7HDWO   = ,E11.4,5X,8HENVELOPE,
               /40X,7HTB    = ,E11.4,4X,7HWL    = ,E11.4,
               /40X,7HTS    = ,E11.4,4X,7HTX    = ,E11.4,
               /40X,7HTSF   = ,E11.4,4X,7HTE    = ,E11.4,
               /40X,7HF     = ,E11.4,4X,7HFEA   = ,E11.4,
               /62X,                    7HFER   = ,E11.4) $
1600   FORMAT(//35X,33HCONDITION AT MINIMUM ALTITUDE OF 1PE11.4,5H FEET
              /61X,9HEALLOW = E11.4
              /61X,9HETOT   = E11.4
              /61X,7HDIM1 = E11.4) $
1601   FORMAT(//35X,33HCONDITION AT MINIMUM ALTITUDE OF 1PE11.4,5H FEET
              /61X,9HEALLOW = E11.4
              /61X,9HQRET   = E11.4
              /61X,7HDIM1 = E11.4) $
1700   FORMAT(//35X,33HCONDITION AT MAXIMUM ALTITUDE OF 1PE11.4,5H FEET
              /61X,9HEALLOW = E11.4
              /61X,9HETOT   = E11.4
              /61X,7HDIM2 = E11.4) $
1701   FORMAT(//35X,33HCONDITION AT MAXIMUM ALTITUDE OF 1PE11.4,5H FEET
              /61X,9HEALLOW = E11.4
              /61X,9HQRET   = E11.4
              /61X,7HDIM2 = E11.4) $
1800   FORMAT(//35X,21HLET DELTA ALTITUDE = 1PE11.4,5H FEET/////19X,
       82HALTITUDE     H RANGE      H RANGE      E ALLOWABLE  E RECEIVE
       D   IMAGE DIAM  TRANS/21X,4HFEET,7X,6HN MILE,9X,3H FT,37X,2HMM)$
1900   FORMAT(18X,1PE11.4,2X,6(E11.4,2X)) $
       TABLEDEF FB(2,11),SYMB1(10),SYMB2(10),ORD(2),AB(4),LINE1(2) $
       READ 1000,AK,WK,DWO,WL,TX,TE $
```

```
FLS 043 T          TMD      F/1.E-2$
FLS 044 T          TDM      AMSIMP.AMSIMP+3$
FLS 045   CARD     READ 1200,W,HB,EALLOW,PRIMEK,ALPHA,TB,F,ABAR,P,PERY,FFA,FER $
FLS 046            TS=0.0 $
FLS 047            IF(W) E (0.0),GO TO EXIT $
FLS 048            CALL AMRUPTS
FLS 049 T          JMP      M/4$
FLS 050            PRINT 1300 $
FLS 051            CALL AIR(HB,PHB,THB,DHB) $
FLS 052            WSCL=0.032*(DHB*W)**0.5 $
FLS 053            IF(TB) E (0.0),TB=(TS-0.0025)*WSCL'GO TO 10 $
FLS 054            IF(TS) E (0.0),TS=0.0025+TB/WSCL'GO TO 10 $
FLS 055            IF(TB) GT ((TS-.0025)*WSCL),TB=(TS-.0025)*WSCL'GO TO 10 $
FLS 056            TS=.0025+TB/WSCL $
FLS 057   10       TSF=.032*TS $
FLS 058            IF(TS) GTE (FB(1,11)),DF=FB(2,11)'GO TO 40 $
FLS 059            IF(TS) LT (FB(1,1)),I=2'GO TO 30 $
FLS 060            DO 20 I=2,11 $
FLS 061            IF(TS) LT (FB(1,I)),GO TO 30 $
FLS 062   20       CONTINUE $
FLS 063   30       DF=FB(2,I-1)+LOGF(TS/FB(1,I-1))*(FB(2,I)-FB(2,I-1))/
FLS 064                                      LOGF(FB(1,I)/FB(1,I-1)) $
FLS 065   40       DFB=360.0*DF $
FLS 066            DFB=DFB*W**0.4*(1./DHB)**0.333 $
FLS 067            DFBM=30.48*DFB $                          DIAMETER IN CM
FLS 068            PRINT 1500,W,AK,HB,WK,DFB,DWO,TB,WL,TS,TX,TSF,TE,F,FEA,FER $
FLS 069            EALLOW=EALLOW*FEA $
FLS 070            QREC=7.95775E10*ABAR*P*PERY*W*TE*TX/(F*F*DFBM*DFBM) $
FLS 071            QRET=1.23E9*QREC/TE*FER $
FLS 072            IF(QRET) GTE (EALLOW),GO TO 710 $
FLS 073            PRINT 1400,W,HB,PERY,TB,FEA,FER $
FLS 074            GO TO CARD $
FLS 075   710      CRITD=4920.*W**.3333 $
FLS 076            EMAX=4.5E-7*PRIMEK*W**.63 $
FLS 077            IF(F)GT(3.0),TERM=FER*EMAX*(110./ALPHA**2+40./ALPHA+2.) $
FLS 078            IF(F)LT(3.0),TERM=FER*EMAX*(675./ALPHA**2+240./ALPHA+13.) $
FLS 079            TE[illegible]ERM*TE*TX $
FLS 080            DS=(17.*DFB)/1.0 $
FLS 081            A=HB-DS $
FLS 082            IF(A)LTE(0.0),A=1.0 $
FLS 083            HR=0.0 $
FLS 084   720      CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
```

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FLS 085          QRET=QRET*T $
FLS 086          IF(ABSF(1.0-QRET/EALLOW))LTE(.025),GO TO 740 $
FLS 087          IF(QRET)LT(EALLOW),A=A+300.'GO TO 720 $
FLS 088    730   ETOT=TERM*(CRITD**2/DS**2)*T $
FLS 089          IF(ABSF(1.0-ETOT/EALLOW))LTE(.025),GO TO 700 $
FLS 090          IF(ETOT)LT(EALLOW),GO TO 700 $
FLS 091          DS=DS+300. $
FLS 092          A=HB-DS $
FLS 093          IF(A)LT(0.0),A=1.0'GO TO 700 $
FLS 094          CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
FLS 095          GO TO 730 $
FLS 096    700   AMIN=A $
FLS 097          IF(HB-A)E(0.0),DIM=17.0'GO TO 701 $
FLS 098          DIM=17.*DFB/(HB-A) $
FLS 099    701   PRINT 1600,AMIN,EALLOW,ETOT,DIM $
FLS 100          GO TO 750 $
FLS 101    740   AMIN=A $
FLS 102          IF(HB-A)E(0.0),DIM=17.0'GO TO 702 $
FLS 103          DIM=17.*DFB/(HB-A) $
FLS 104    702   PRINT 1601,AMIN,EALLOW,QRET,DIM $
FLS 105          GO TO 750 $
FLS 106    750   DS=(17.*DFB)/1.0 $
FLS 107          A=HB+DS $
FLS 108          IF(A)GTE(100000.),A=100000. $
FLS 109    770   CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
FLS 110          QREC=7.95775E10*ABAR*P*PERY*W*TE*TX/(F*F*DFBM*DFBM) $
FLS 111          QRET=1.23E9*QREC/TE*FER*T $
FLS 112          IF(ABSF(1.0-QRET/EALLOW))LTE(.025),GO TO 790 $
FLS 113          IF(QRET)LT(EALLOW),DS=DS-300.'A=HB+DS'GO TO 770 $
FLS 114    760   ETOT=TERM*(CRITD**2/DS**2)*T $
FLS 115          IF(ABSF(1.0-ETOT/EALLOW))LTE(.025),GO TO 780 $
FLS 116          IF(ETOT)LT(EALLOW),GO TO 780 $
FLS 117          DS=DS+300. $
FLS 118          A=HB+DS $
FLS 119          IF(A)GT(100000.),A=100000.'GO TO 780 $
FLS 120          CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
FLS 121          GO TO 760 $
FLS 122    780   AMAX=A $
FLS 123          IF(HB-A)E(0.0),DIM=17.0'GO TO 781 $
FLS 124          DIM=17.*DFB/(A-HB) $
FLS 125    781   PRINT 1700,AMAX,EALLOW,ETOT,DIM $
FLS 126          GO TO 800 $
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790     AMAX=A $
        IF(HB-A)E(0.0),DIM=17.0'GO TO 782 $
        DIM=17.*DFB/(A-HB) $
782     PRINT 1701,AMAX,EALLOW,QRET,DIM $
        GO TO 800 $
800     AMAXI=1000.*INTF(AMAX/1000.) $
        AMINI=1000.*INTF((AMIN+999.)/1000.) $
        IF(AMAXI-AMINI) GT (40000.),DELTA=5000.'GO TO 120 $    SET UP A
        IF(AMAXI-AMINI) GT (20000.),DELTA=2000.'GO TO 120 $    DELTA ALT
        IF(AMAXI-AMINI) GT (10000.),DELTA=1000.'GO TO 120 $   FROM MIN TO
        IF(AMAXI-AMINI) GT ( 4000.),DELTA= 500.'GO TO 120 $    MAX ALT
        IF(AMAXI-AMINI) GT ( 2000.),DELTA= 200.'GO TO 120 $
        DELTA=100. $
120     AMINI=INTF(AMINI/DELTA)*DELTA $  BOTTOM ALTITUDE TO NEAREST KFT
        LAST=(AMAXI-AMINI)/DELTA+1.0 $    NUMBER DELTA ALTS TO REACH TOP
        PRINT 1800,DELTA $
        DS=(17.*DFB)/1.0 $
        DO 860 IALT=1,LAST $
        DELD=1000. $
        IF(W)LTE(10.),DELD=250. $
        A=AMINI+(IALT-1)*DELTA $
810     ABHR=ABSF(DS**2-(HB-A)**2) $
        HR=SQRTF(ABHR) $
        CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
        IF(IG)E(-3),QRET=0.0'GO TO 840 $ CHECK EARTH INTERSECTION
        QREC=7.95775E10*ABAR*P*PERY*W*TE*TX/(F*F*DFBM*DFBM) $
        QRET=1.23E9*QREC/TE*FER*T $
        IF(ABSF(1.0-QRET/EALLOW))LTE(.025),GO TO 840 $
        IF(QRET)LT(EALLOW),GO TO 850 $
880     ETOT=TERM*(CRITD**2/DS**2)*T $
        IF(ABSF(1.0-ETOT/EALLOW))LTE(.025),GO TO 870 $
        IF(ETOT)LT(EALLOW),GO TO 870 $
        DS=DS+DELD $
        ABHR=ABSF(DS**2-(HB-A)**2) $
        HR=SQRTF(ABHR) $
        CALL TRANS(A,HB,HR,PHB,DHB,AK,WK,DWO,WL,T) $
        IF(IG)E(-3),ETOT=0.0'GO TO 870 $ CHECK EARTH INTERSECTION
        GO TO 880 $
870     DIM=17.*DFB/SQRTF(HR**2+(HB-A)**2) $
        HRMILE=HR/6080. $
        PRINT 1900,A,HRMILE,HR,EALLOW,ETOT,DIM,T $
        GO TO 860 $
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```
FLS 169  840    DIM=17.*DFB/SQRTF(HR**2+(HB-A)**2) $
FLS 170         HRMILE=HR/6080. $
FLS 171         PRINT 1900,A,HRMILE,HR,EALLOW,QRET,DIM $
FLS 172         GO TO 860 $
FLS 173  850    DS=DS-DELD $
FLS 174         GO TO 810 $
FLS 175  860    CONTINUE $
FLS 176         GO TO CARD $
FLS 177  EXIT   CALL RSYS $
FLS 178 T       JMP     IOHTAB.RUNALLS
FLS 179 T       JMP     M/4S
FLS 180 TFB     F/.001S
FLS 181 T       F/.1S
FLS 182 T       F/.002S
FLS 183 T       F/.135S
FLS 184 T       F/.0045S
FLS 185 T       F/.19S
FLS 186 T       F/.01S
FLS 187 T       F/.265S
FLS 188 T       F/.02S
FLS 189 T       F/.345S
FLS 190 T       F/.05S
FLS 191 T       F/.4675S
FLS 192 T       F/.15S
FLS 193 T       F/.65S
FLS 194 T       F/1.0S
FLS 195 T       F/1.0S
FLS 196 T       F/2.0S
FLS 197 T       F/1.09S
FLS 198 T       F/4.0S
FLS 199 T       F/1.165S
FLS 200 T       F/8.0S
FLS 201 T       F/1.2S
FLS 202         END $
FLS 203         ABS     2.EYE SAFE FLASH.GO
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Ralph G. Allen, Jr.
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Donald J. Isgitt
Brian E. Arment
John A. Russell

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13. ABSTRACT

~~This~~ report is intended to be used as an aid to military mission planners in determining allowable proximity to a nuclear fireball from the standpoints of permanent retinal injury and the temporary effects of flashblindness. Pertinent physical and physiological phenomena are discussed in moderate detail; the nucleus of the work being a family of curves which indicate acceptable separation distances for the prevention of retinal burns and flashblindness. Detailed instructions for approximating acceptable separation distances using a slide rule are included as an appendix. ( )

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